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CONTENTS

PROCEEDINGS

PAGE
Summary of Proceedings of the Forty-Eighth Annual Meeting 1
Preparations for the Future of the A.S.T.M.: Annual Address by the President—P. H. Bates 14
Annual Report of the Executive Committee 21

COMMITTEE REPORTS

Ferrous Metals

Report of Committee A-2 on Wrought Iron 65
Report of Committee A-5 on Corrosion of Iron and Steel 66
  Report of Subcommittee III on Inspection of Annapolis Tests 67
  Report of Subcommittee VIII on Field Tests of Metallic Coatings 69
  Report of Wire Inspection Committee on Field Tests of Wire and Wire Products 70
Report of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys 87
Report of the Research Committee on Fatigue of Metals 91
Report of Joint Research Committee on Effect of Temperature on the Properties of Metals 92
Report of Joint Committee on Filler Metal 94

Non-Ferrous Metals

Report of Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors 96
Report of Committee B-2 on Non-Ferrous Metals and Alloys 102
Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys 105
Report of Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys 108
Report of Committee B-5 on Copper and Copper Alloys, Cast and Wrought 111
  Appendix. Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought 120
Report of Committee B-6 on Die-Cast Metals and Alloys 134
Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought 137
  Appendix I. Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought 141
  Appendix II. A Comparison of the Performance of Anodic Coatings Exposed to Salt Spray and to the Weather—Prepared by J. D. Edwards 146
Report of Committee B-8 on Electrodeposited Metallic Coatings 149
  Report of Subcommittee II on Performance Tests 152
  Appendix. Recommendations Affecting Standards for Electrodeposited Metallic Coatings 154

Cementitious, Ceramic, Concrete, and Masonry Materials

Report of Committee C-1 on Cement 156
  Appendix I. Proposed Recommendations Affecting Standards on Cement 160
  Appendix II. Proposed Specifications for Portland Blast-Furnace Slag Cement 162
  Appendix III. Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Prepared by Dalton G. Miller and Charles G. Snyder 165
  Appendix IV. Proposed Method of Test for Fineness of Portland Cement by Air Permeability Apparatus 195
Report of Committee C-4 on Clay Pipe 200
Report of Committee C-5 on Fire Tests of Materials and Construction 201

PAGE
Report of Committee C-7 on Lime 203
  Appendix. Proposed Revision of the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 – 38 T) 206
Report of Committee C-8 on Refractories 208
Report of Committee C-12 on Mortars for Unit Masonry 213
Report of Committee C-15 on Manufactured Masonry Units 214
Report of Committee C-16 on Thermal Insulating Materials 216

Miscellaneous Materials

Report of Committee D-1 on Paint, Varnish, Lacquer, and Related Products 220
Report of Committee D-2 on Petroleum Products and Lubricants 228
  Report of Technical Committee A on Gasoline 233
  Results of Tests on Method for Estimating Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants 237
  Appendix I. Proposed Method of Test for Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants 244
  Appendix II. Proposed Method of Test for Total Olefinic and Aromatic Hydrocarbons in Gasoline 247
Report of Committee D-3 on Gaseous Fuels 253
Report of Committee D-5 on Coal and Coke 255
Report of Committee D-6 on Paper and Paper Products 257
  Appendix. Proposed Methods of Test for Smoothness of Paper 260
Report of Committee D-7 on Wood 265
  Appendix. Methods Used for the Measurement of the Moisture Content of Wood—Prepared by M. E. Dunlap 269
Report of Committee D-9 on Electrical Insulating Materials 275
  Appendix I. Recommendations Affecting Standards on Electrical Insulating Materials 283
  Appendix II. Proposed Methods of Testing Askarels 292
  Appendix III. Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service 302
Report of Sectional Committee C59 on Electrical Insulating Materials 310
Report of Committee D-10 on Shipping Containers 311
Report of Committee D-11 on Rubber and Rubber-Like Materials 312
Report of Committee D-12 on Soaps and Other Detergents 319
  Appendix. Tentative Revision of Standard Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 – 44) 322
Report of Committee D-13 on Textile Materials 323
  Appendix. Recommendations Affecting Standards for Textile Materials 329
Report of Committee D-14 on Adhesives 335
Report of Committee D-16 on Industrial Aromatic Hydrocarbons 337
  Appendix I. Cooperative Distillation Tests 340
  Appendix II. Report of Special Committee on Aromatic Petroleum Solvents 348
Report of Committee D-17 on Naval Stores 349
Report of Committee D-18 on Soils for Engineering Purposes 354
Report of Committee D-19 on Water for Industrial Uses 356
  Appendix. Proposed Methods of Test for Dissolved Oxygen in Industrial Waters 360
Determination of Dissolved Oxygen in Industrial Waters (*see* ASTM BULLETIN, *No. 137, December, 1945, p. 19*)
Report of Committee D-20 on Plastics 369
  Appendix I. Recommendations Affecting Standards on Plastics 374
  Appendix II. Flexural Properties of Plastics—Summary of Test Results Obtained in Committee D-20—W. A. Zinzow 376
  Discussion 389

Miscellaneous Subjects

Report of Committee E-3 on Chemical Analysis of Metals 391
Report of Committee E-10 on Standards 395

TECHNICAL PAPERS

Metals

Fracture Testing of Alloy Steels for Aircraft Engine Forgings—R. D. Haworth, Jr. and A. F. Christian 407
  Discussion 441

PAGE

The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C.—D. J. McAdam, Jr., G. W. Geil, and R. W. Mebs 448
Discussion 482
Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr 486
Discussion 504
A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel—H. F. Moore 507
Discussion 522
The Effect of Overstress in Fatigue on the Endurance Life of Steel—J. B. Kommers .. 532
Discussion 542
A Sulfur Print Method for the Study of Crack Growth in the Corrosion-Fatigue of Metals—R. C. Brumfield 544
A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere—H. R. Copson 554
Discussion 581
The Effect of the Iron Content of Cupro-Nickel on its Corrosion Resistance in "Sea Water"—A. W. Tracy and R. L. Hungerford 591
Discussion 613
Observations on the Appearance Welding of Malleable Castings—H. A. Schwartz, Ira Young, and James Hedberg 618
Discussion 626
The Manufacture of Heavy-Wall Pipe 12$\frac{3}{4}$ to 24 in. Outside Diameter—E. C. Wright (see ASTM BULLETIN, *No. 133, March, 1945, p. 19)*
The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid—David J. Mack 629
Practical Electric Resistance Strain Gage Procedures for Structural Tests on Ships—W. V. Bassett 651
Discussion 667
Single-Strip Compression Test for Sheet Materials—Harry LaTour and Don S. Wolford 671
Discussion 689
Compression Testing of Magnesium Alloy Sheet—A. A. Moore and J. C. McDonald 698
Cast-to-Size Impact Specimens for Aluminum Sand Casting Alloys—R. A. Quadt ... 705
Electrical Conductivity of Conductors—L. F. Roehmann 711
A Variable Cycle Alternate Immersion Corrosion Testing Machine—C. H. Mahoney, A. L. Tarr, and K. A. Skeie 719
Memo on Cavitation—Frank N. Speller (see ASTM BULLETIN, *No. 133, March, 1945, p. 21)*
Surface-Conversion Coatings—George W. Jernstedt (see ASTM BULLETIN, *No. 137, December, 1945, p. 29)*

Symposium on Magnetic Particle Testing

Summary of Proceedings of the Philadelphia District Committee Meeting—Symposium on Magnetic Particle Testing 722

Cement, Concrete, Masonry Materials

Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars—G. J. Fink and Emil Trattner 723
The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer 732
Discussion 753
Effect of Heat on Portland Cements Containing Vinsol Resin—Leonard Bean and Albert Litvin 766
A Comparison of Absorption and Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt 771
Stress Conditions for the Failure of Saturated Concrete and Rock—K. Terzaghi 777
Discussion 793
Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete—Bryant Mather 802
Discussion 810
Automatic Accelerated Freezing-and-Thawing Apparatus for Concrete—Charles E. Wuerpel and Herbert K. Cook 813
The Effect of Repeated Loading on the Bond Strength of Concrete—C. W. Muhlenbruch 824

PAGE
Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders—Gerald Pickett 846
Discussion 864
Test Criterion for an Incombustible Material—N. P. Setchkin and S. H. Ingberg 866
Discussion 876
Glass—A Summary of Its Development as an Art and as a Science—F. C. Flint (see ASTM Bulletin, *No. 132, January, 1945, p. 19)*

Miscellaneous

Fatigue Tests of a Laminated Mitscherlich-Paper Plastic—William N. Findley 878
Discussion 904
The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics—E. M. Schoenborn, George R. Proctor, and Jaime Carvajal .. 910
Discussion 923
Dimensional Stability of Plastics—Robert Burns 926
The Effect of Specimen Shape on the Compressive Strength Properties of Laterally Supported Plywood Specimens—J. A. Liska 935
A New Machine for Measuring Wear Resistance of Walkway Materials—A. W. Cizek, Jr., D. H. Kallas, and H. Nestlen 943
Discussion 951
Effect of Dimensions of Specimens upon the Precision of Strength Data—John Tucker, Jr. 952
Discussion 960
The Maximum Stresses Present at Failure of Brittle Materials—John Tucker, Jr. . 961
Discussion 974
Effect of Length on the Strength of Compression Test Specimens—John Tucker, Jr. 976
Metal Cleaning: I—Indirect Performance Tests—Jay C. Harris 985
Metal Cleaning: II—Soil Removal Performance Methods—Jay C. Harris 997
The Determination of the Terpene Alcohol Content of Steam-Distilled Pine Oil—V. E. Grotlisch and H. N. Burstein 1015
Methods Used for the Measurement of the Moisture Content of Wood—M. E. Dunlap, Appendix, Report of Committee D-7 on Wood (see p. 269)
Flexural Properties of Plastics—Summary of Test Results—W. A. Zinzow, Appendix II, Report of Committee D-20 on Plastics (see p. 376)

MISCELLANEOUS PAPERS PUBLISHED IN ASTM BULLETIN

Symposium on Neutralization Number (see ASTM Bulletin, *No. 134, May, 1945)*
  Introduction—H. P. Ferguson (p. 48)
  Neutralization Number from the Viewpoint of the Industrial Engineer—C. L. Pope (p. 48)
  Neutralization Number from the Viewpoint of the Turbine Engineer—I—F. C. Linn (p. 50)
  Neutralization Number from the Viewpoint of the Turbine Engineer—II—G. H. von Fuchs (p. 51)
  Neutralization Number from the Viewpoint of the Automotive Engineer—H. R. Wolf (p. 52)
  A Comparison of the Salt Method with A.S.T.M. Method for Determining the Acidity of Lubricating Oils—C. M. Loane (p. 55)
Determination of Gum Values by the I.P.T. and A.S.T.M. Air Jet Gum Methods—E. L. Walters and D. L. Yabroff (see ASTM Bulletin, *No. 135, August, 1945, p. 40)*
Cooperative Committees Developing Test Methods for Lubricating Greases—T. G. Roehner (see ASTM Bulletin, *No. 133, March, 1945, p. 31)*
Past History of A.S.T.M. Lubricating Grease Test Methods—H. A. McConville (see ASTM Bulletin, *No. 133, March, 1945, p. 29)*
Life Testing of Lubrication Oil—H. C. Mougey (see ASTM Bulletin, *No. 132, January, 1945, p. 15)*
A New Method for the Mechanical Analysis of Soils—Raul Valle-Rodas (see ASTM Bulletin, *No. 135, August, 1945, p. 44)*
Some Factors in the Interpretation of Small-Scale Tests for Fire-Retardant Wood—F. W. Gottschalk (see ASTM Bulletin, *No. 136, October, 1945, p. 40; Discussion, No. 138, January, 1946, p. 49.)*
A Simplified Method for the Determination of the Specific Gravity of Wood and Plastics—E. George Stern and Paul S. Dear (see ASTM Bulletin, *No. 135, August, 1945, p. 35)*

PAGE

A Rubber Housing for Waterproofing the Bonded-Wire Strain Gage—Douglas McHenry (*see* ASTM BULLETIN, *No. 133, March, 1945, p. 18*)

High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds—G. D. McCarthy, A. E. Juve, H. Boxser, M. Sanger, S. R. Doner, E. N. Cunningham, J. F. McWhorter, and R. H. Crossley (*see* ASTM BULLETIN, *No. 132, January, 1945, p. 33*)

The Effect of Fuels and Gasoline on Synthetic Rubber Compounds—Report of Fluid Aging Committee (*see* ASTM BULLETIN, *No. 135, August, 1945, p. 33*)

An Automotive Tire Fatigue Machine—John N. Kenyon (*see* ASTM BULLETIN, *No. 136, October, 1945, p. 9*)

Standard Fatigue Tester for Use by the Rayon Manufacturers—Report to Committee D-13—W. H. Bradshaw (*see* ASTM BULLETIN, *No. 136, October, 1945, p. 13*)

Comparative Fatigue Test Data—C. S. Venable (*see* ASTM BULLETIN, *No. 136, October, 1945, p. 17*)

Statistical Comparison of Rayon Tire Cord Fatigue Testing Machines—C. B. Budd and L. Larrick (*see* ASTM BULLETIN, *No. 136, October, 1945, p. 19*)

A Suggested Method for Thorough Testing of Antiseptic Fabrics—Louis C. Barail (*see* ASTM BULLETIN, *No. 136, October, 1945, p. 25*)

Tomorrow's Textiles—Yesterday's Test Methods—J. B. Goldberg (*see* ASTM BULLETIN, *No. 135, August, 1945, p. 47*)

The pH of Some Standard Buffer Solutions from 0 to 60 C. and the Calibration of Glass Electrode pH Meters—George G. Manov and S. F. Acree (*see* ASTM BULLETIN, *No. 137, December, 1945, p. 25*)

An Automatic Heat Distortion Recorder for Plastics—George A. Heirholzer and R. F. Boyer (*see* ASTM BULLETIN, *No. 134, May, 1945, p. 37*)

General Properties of Industrial Radiographic Films—Herman E. Seemann (*see* ASTM BULLETIN, *No. 134, May, 1945, p. 17*)

Relation Between Life Testing and Conventional Tests of Materials—R. E. Peterson (*see* ASTM BULLETIN, *No. 133, March, 1945, p. 9*)

A New Coating Thickness Gage—S. Lipson (*see* ASTM BULLETIN, *No. 135, August, 1945, p. 20*)

A Suggested New Parameter for Fatigue Strength Analysis—Victor Seliger (*see* ASTM BULLETIN, *No. 132, January, 1945, p. 29*)

Symposium on Adhesives

Summary of Proceedings of the Symposium on Adhesives, Atlantic City, October, 1945 1023

Subject Index 1024
Author Index 1049

INSERT PLATES

(Plates appear in Envelope on Inside Back Cover)

Plates I, II, and III. Wire Inspection Reports, Report of Committee A-5
Plate IV. Data on Performance Tests, Report of Committee B-8
Plate V. Questionnaire on Transformer Oil Tests, Report of Committee D-9

SUMMARY OF PROCEEDINGS

OF THE

FORTY-EIGHTH ANNUAL MEETING

New York, N. Y., June 27, 1945

The following Summary records the action taken by the Society at the Annual Meeting on the Recommendations Affecting Standards appearing in the annual reports of the standing committees. In the individual committee reports attention is called through an editorial footnote to any modifications of the recommendations or where the recommendations of the committee were not approved. In all other instances it is to be understood that the recommendations were approved as submitted by the committee. The new and revised standards and tentatives are published in the 1945 Supplement to Book of A.S.T.M. Standards, Parts I, II, and III. Except as noted, the reports and paper appear in this volume.

This summary of the Forty-eighth Annual Meeting of the American Society for Testing Materials, held at the Hotel Pennsylvania, New York, N. Y., June 27, 1945, is a record of the transactions of the meeting including the actions taken on the various recommendations submitted by the standing committees. Due to restrictions on travel resulting from recommendations of the Office of Defense Transportation, the program for the Annual Meeting had been confined to the transaction of necessary Society business which could be completed in a single session. The meeting was called to order at 2 p.m. with President P. H. Bates in the chair.

The registered attendance of the meeting is as follows: Members present or represented, 90; guests, 3; total, 93.

There were 43 reports presented. The record with respect to each report has been briefed, the recommendations in the reports having been grouped to show first those matters that were approved for reference to letter ballot of the Society, which comprise the adoption of tentatives as standard and the adoption of revisions in standards. Accordingly, wherever the action is reported as "Adopted as Standard" or "Adopted as Standard, Revisions in" it is understood that this indicates approval of the Annual Meeting for reference to letter ballot of the Society. The various recommendations so recorded are included in the 1945 Letter Ballot.[1]

Actions affecting tentatives were taken by Committee E-10 on Standards at a meeting held in the morning preceding the Annual Meeting. The actions taken by Committee E-10 were reported to the Society and, for the sake of convenience, the various recommendations are listed in this summary in connection with the report of the committee submitting such recommendations, each group being designated by an asterisk (*). On certain of the submittals to Committee E-10 action was deferred pending completion of the letter ballot vote in the originating committee. Such items are included in this summary with appropriate notation.

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[1] The 1945 letter ballot on amendments of Society By-laws and on recommendations affecting A.S.T.M. standards, distributed to the Society membership, was canvassed on September 15, 1945 and all actions were approved.

Opening Remarks by President Bates

President P. H. Bates extended a very cordial welcome to the members and guests in opening the Forty-eighth Annual Meeting of the Society. He stated that, while the program for the meeting had been reduced to a minimum, the Society had had a very successful year as evidenced by the progress and accomplishments in its standardization and research activities which are covered in detail in the many reports to be presented at this Annual Meeting, and also in the numerous Annual Meeting papers published or to be issued later in the year.[2]

Minutes of Forty-seventh Annual Meeting

The Minutes of the Forty-seventh Annual Meeting were approved as published in the 1944 Proceedings.[3]

Executive Committee

This report, presented by Secretary-Treasurer C. L. Warwick, covered a review of membership, publications, finances, new headquarters, and administrative matters dealing with committee activities and the Society's relations with various other organizations. Reference was made to important new developments growing out of critical examination of Society problems by the Special Study Committee, including extension of work in the standardization of tests and specifications for ultimate consumer goods; the study, development, and standardization of methods of test of simple or composite materials in actual or simulated service conditions; and changes in methods of publication of technical papers. The Secretary-Treasurer described in some detail the changes in the administration of Society affairs which involve the establishment of a Board of Directors as the governing body of the Society, and require amendments of the charter and by-laws of the Society.

Proposed Amendment of Society By-laws

The proposed Amendments of the By-laws submitted to the Society under date of May 25, 1945, through Letter Circular to Members No. 264, and recommended by the Executive Committee for approval, were then on motion approved for reference to a letter ballot vote of the Society for adoption.[4]

Proposed Amendment of Society Charter

The Secretary-Treasurer called the attention of the meeting to the fact, as noted in the Report of the Executive Committee, that the proposed substitution of a Board of Directors for an Executive Committee as the governing body of the Society will necessitate an amendment of the charter of the Society which, in turn, requires court approval under the provisions of the laws of the Commonwealth of Pennsylvania. In accordance with those provisions, the Secretary-Treasurer offered on behalf of the Executive Committee the following resolution:

RESOLUTION

WHEREAS, the annual meeting of the Society has voted to refer certain amendments of the By-laws of the Society to a letter ballot of the entire membership in accordance with the terms of Article X of the By-laws; and

WHEREAS, these amendments include, *inter alia*, a proposal to substitute a Board of Directors for an Executive Committee as the body in which the general management of the Society will be vested; and

WHEREAS, the Charter of the Society specifically names an Executive Committee in which such management shall be vested; and

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[2] See list of technical papers on p. 12.

[3] Summary of Proceedings of the Forty-seventh Annual Meeting; *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 1 (1944).

[4] The amended By-laws were approved by letter ballot vote of the Society canvassed on September 15, 1945. The By-laws as revised are published in the 1945 A.S.T.M. Year Book, p. 433.

WHEREAS, amendment of Sections 6 and 8 of the Charter is necessary before the related amendments of the By-laws may become effective; and

WHEREAS, such purpose may be effected by changing Sections 6 and 8 of the Charter to read as follows:

"Section 6. The management of the said corporation shall be vested in a Board of Directors, consisting of the President, two Vice-Presidents, fifteen Directors, and the last three Past-Presidents continuing to be members, and such other officers as the corporation may from time to time appoint."

"Section 8. The By-laws of this corporation shall be admitted and taken to be its laws subordinate to the statute aforesaid; this charter; Constitution and Laws of the Commonwealth of Pennsylvania, and the Constitution of the United States; they shall be altered and amended as provided for by the By-laws themselves; and shall prescribe the powers and functions of the Board of Directors herein mentioned and those to be hereafter elected, the times and places of meetings of the Board and this corporation; the number of members who shall constitute a quorum at the meetings of the corporation, and the Board; the qualifications and manner of electing members; the manner of electing officers; and the powers and duties of such officers; and all other concerns and internal arrangements of the said corporation."

Now, Therefore, Be It

RESOLVED, that the American Society for Testing Materials in annual meeting assembled, after due and legal notice in accordance with the laws of the Commonwealth of Pennsylvania, approves the above proposed amendments of Sections 6 and 8 of the Charter of the Society and authorizes the President to present to the court appropriate Articles of Amendment to the Charter and to take such further action as may be required by the laws of the Commonwealth of Pennsylvania to effectuate the aforesaid amendments to the Charter.

It was explained that the members of the Society had been informed in Letter Circular No. 264 that this resolution would be offered at the Annual Meeting, and an opportunity had been given to members unable to attend the Annual Meeting to express a vote on the resolution. The Secretary-Treasurer reported that 1935 ballots had been received from the members, of which 1930 were affirmative and 5 negative.

The meeting then adopted the above quoted resolution without a dissenting vote.

On motion, the Report of the Executive Committee was accepted for publication in the *Proceedings* of the Society.

Committee A-1 on Steel

Report presented by title.

Committee A-2 on Wrought Iron

Report presented by the chair and the following action taken:

Adopted as Standard, Revisions in:

Spec. for Welded Wrought Iron Pipe (A 72 – 39)

Committee A-5 on Corrosion of Iron and Steel

Report presented by title, including a detailed summary of the latest inspections of the field tests of wire and wire products, with the following recommendation:

Editorial Change Accepted in:

Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron or Steel Articles (A 239 – 41), comprising a change in Section 1 on Scope replacing the words "pipe and tubing" by "electrical metallic tubing and rigid conduit pipe."

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys

Report presented by title.

Committee B-1 on Copper and Copper Alloy Wires for Electrical Conductors

Report presented by J. H. Foote, chairman, and the following actions taken:

Adopted as Standard, Revisions in:

Spec. for Soft or Annealed Copper Wire (B 3 – 41)

Spec. for Tinned Soft or Annealed Copper Wire for Electrical Purposes (B 33 – 39)

Spec. for Soft Rectangular and Square Copper Wire for Electrical Conductors (B 48 – 42)

*Accepted as Tentative, Revisions in:**

Spec. for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (B 172 – 42 T)
Spec. for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members for Electrical Conductors (B 173 – 42 T)
Spec. for Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 – 42 T)
Spec. for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes (B 189 – 44 T)

The following recommendation was presented to Committee E-10, but action was deferred pending completion of letter ballot vote in Committee B-1:[5]

Proposed Revisions in Tentative:

Test for Resistivity of Copper and Copper-Alloy Electrical Conductors (B 193 – 44 T)

Committee B-2 on Non-Ferrous Metals and Alloys

Report presented by title.

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys

Report presented by title.

Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys

Report presented by Dean Harvey, chairman, and the following actions taken:[6]

Adopted as Standard, Revisions in:

Test for Temperature-Resistance Constants of Alloy Wires for Precision Resistors (B 84 – 36), comprising the addition of the following paragraph to Section 7:

In an automatically controlled bath, the temperature of the bath at any time during the test at any temperature level shall not differ from its mean temperature by more than 0.2 C. In a manually controlled bath, the rate of change of temperature shall not exceed 0.2 C. per min.

Test for Temperature-Resistance Constants of Sheet Materials for Shunts and Precision Resistors (B 114 – 39), comprising the addition to Section 6 of the same paragraph as given above for Method B 84.

Editorial Changes Accepted in:

Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (B 70 – 39), comprising the following changes in Section 5 (*b*): In the third line substitute "power lost in" for "energy liberated." Also in the last sentence replace "energy" by "power" and under the formula add "W = power loss in watts."

Test for Thermoelectric Power of Electrical-Resistance Alloys (B 77 – 33), making Sections 6 (*a*), (*b*), and (*c*) read as follows:

(*a*) The method in which a potentiometer is used to compare the unknown emf. with that of a standard cell.

(*b*) The method in which the unknown emf. is equated to the difference of potential between the terminals of a standard resistor when a measured current flows through it.

(*c*) The method in which the emf. is measured by the deflection of a suitable measuring instrument.

It was announced that Committee B-4 would present revisions in a number of tentatives to the Society through Committee E-10 subsequent to the annual meeting.

Committee B-5 on Copper and Copper Alloys, Cast and Wrought

Report presented by G. H. Harnden, chairman, and the following actions taken:

Adopted as Standard:

Classification of Cast Copper-Base Alloys (B 119 – 40 T), as revised
Spec. for Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 – 44 T)
Spec. for Brass Wire (B 134 – 44 T), as revised
Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (B 153 – 41 T), as revised
Method of Mercurous Nitrate Test for Copper and Copper Alloys (B 154 – 41 T), as revised
Spec. for Copper-Alloy Condenser Tube Plates (B 171 – 42 T), as revised

Adopted as Standard, Revisions in:

Spec. for Copper Bars for Locomotive Staybolts (B 12 – 42)
Spec. for Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 – 44)
Spec. for Copper Pipe, Standard Sizes (B 42 – 43)
Spec. for Brass Pipe, Standard Sizes (B 43 – 42)

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* These recommendations were accepted by Committee E-10 on Standards.

[5] This recommendation was approved by Committee B-1 and accepted by Committee E-10 on January 14, 1946.

[6] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee B-4, which ballot has been favorable and the results are given in the report of the committee, see p. 108.

Spec. for Seamless Copper Tubing, Bright Annealed (B 68 – 43)
Spec. for Copper Water Tube (B 88 – 41)
Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 44)
Spec. for Copper-Silicon Alloy Wire for General Purposes (B 99 – 42)
Spec. for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 43)
Spec. for Manganese Bronze Rods, Bars, and Shapes (B 138 – 43)
Spec. for Leaded Red Brass (Hardware Bronze) Rods, Bars and Shapes (B 140 – 43)

*Accepted as Tentative:**

Spec. for Beryllium-Copper Alloy Strip
Spec. for Beryllium-Copper Alloy Strip, Special Grade
Spec. for Beryllium-Copper Alloy Rod and Bar
Spec. for Beryllium-Copper Alloy Wire
Spec. for Copper-Silicon and Copper-Silicon-Zinc Alloy Sand Castings

*Accepted as Tentative, Revisions in:**

Spec. for Naval Brass Rods, Bars, and Shapes (B 21 – 44 T)
Spec. for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 – 44 T)
Spec. for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 44 T)
Spec. for Seamless Copper Tubes (B 75 – 43 T)
Spec. for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 – 42 T)
Spec. for Copper Rods, Bars, and Shapes (B 133 – 44 T)
Spec. for Miscellaneous Brass Tubes (B 135 – 43 T)
Spec. for Phosphor Bronze Rods, Bars, and Shapes (B 139 – 44 T)
Spec. for High-Leaded Tin-Bronze Sand Castings (B 144 – 44 T)
Spec. for Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 – 44 T)
Spec. for Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 44 T)
Spec. for Aluminum-Bronze Sand Castings (B 148 – 44 T)
Spec. for Aluminum Bronze Rods, Bars, and Shapes (B 150 – 44 T)
Spec. for Copper-Nickel-Zinc Alloy Rod, Bar, and Wire (B 151 – 44 T)
Spec. for Copper Sheet, Strip, and Plate (B 152 – 44 T)
Spec. for Phosphor Bronze Wire (B 159 – 44 T)
Spec. for Copper Bus Bars, Rods, and Shapes (B 187 – 44 T)
Spec. for Copper Bus Pipes and Tubes (B 188 – 44 T)

*Withdrawal of Standard and Tentative:**

Spec. for Phosphor Tin (B 51 – 42)
Spec. for Beryllium-Copper Alloy Rods, Bars, Sheet, Strip, and Wire (B 120 – 41 T)

Committee B-6 on Die-Cast Metals and Alloys

Report presented by title.

Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought

Report, including the appended paper by J. D. Edwards on "A Comparison of the Performance of Anodic Coatings Exposed to Salt Spray and to the Weather" was presented by the chair and the following actions taken:

Adopted as Standard:

Test for Sealing of Anodically Coated Aluminum (B 136 – 40 T)
Test for Weight of Coating on Anodically Coated Aluminum (B 137 – 40 T)
Test for Dielectric Strength of Anodized Aluminum (B 110 – 39 T), with revision in title

Adopted as Standard, Revisions in:

Spec. for Magnesium Ingot and Stick for Remelting (B 92 – 41)

*Accepted as Tentative:**

Spec. for Magnesium-Base Alloy Permanent Mold Castings

*Accepted as Tentative, Revisions in:**

Spec. for Magnesium-Base Alloy Sand Castings (B 80 – 44 T)
Spec. for Magnesium-Base Alloy Sheet (B 90 – 44 T)
Spec. for Magnesium-Base Alloy Forgings (B 91 – 44 T)
Spec. for Magnesium-Base Alloys in Ingot Form for Sand Castings and Die Castings (B 93 – 44 T)
Spec. for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 44 T)

Report of Committee B-8 on Electrodeposited Metallic Coatings

Report presented by C. H. Sample, secretary, and the following actions taken:

Adopted as Standard:

Spec. for Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 - 41 T), as revised

The following recommendations were presented to Committee E-10, but action was deferred pending completion of letter ballot vote in Committee B-8:[7]

Proposed Tentatives:

Spec. for Electrodeposited Coatings of Lead on Steel, formerly Emergency Specifications ES - 31
Spec. for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces

Proposed Revisions in Tentatives:

Spec. for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 41 T)
Test for Local Thickness of Electrodeposited Coatings (A 219 - 40 T)
Spec. for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 - 41 T)
Rec. Practice for Chromium Plating on Steel for Engineering Use (B 177 - 43 T)

Joint Committee on Filler Metal

Report presented by title.

Research Committee on Fatigue of Metals

Report presented by title.

Joint Research Committee on Effect of Temperature on the Properties of Metals

Report presented by title.

Committee C-1 on Cement

Report presented by title, with the following recommendations:

Accepted for Publication as Information Only:

Proposed Spec. for Portland Blast-Furnace Slag Cement.
Proposed Method of Test for Fineness of Portland Cement by the Air Permeability Apparatus

Committee C-4 on Clay Pipe

Report presented by title.

Committee C-5 on Fire Tests of Materials and Construction

Report presented by title.

Report of Committee C-7 on Lime

Report presented by title, and the following actions taken:

*Accepted as Tentative, Revisions in:**

Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 - 44)
Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 - 38 T), with the addition of the following explanatory note to the section on calculation of unhydrated oxides:

> NOTE 3.—It is recognized that the results of the above method of computation may not be in strict accord with the actual composition of the material. Experience indicates, however, that these results provide an index to the performance of the material in practice. The value obtained by this computation shall be reported to the nearest 0.5 per cent.

Report of Committee C-8 on Refractories

Report presented, in the absence of the chairman, by R. B. Sosman, and the following actions taken:

Adopted as Standard:

Method of Panel Test for Resistance to Thermal and Structural Spalling of Fireclay Plastic Refractories (C 180 - 43 T)
Test for Workability Index of Fireclay Plastic Refractories (C 181 - 43 T)

Adopted as Standard, Revisions in:

Methods of Chemical Analysis of Refractory Materials (C 18 - 41)
Method of Panel Test for Resistance to Thermal and Structural Spalling of Refractory Brick (C 38 - 42)
Definitions of Terms Relating to Refractories (C 71 - 42)
Method of Panel Test for Resistance to Thermal and Structural Spalling of High Heat Duty Fireclay Brick (C 107 - 42)
Method of Panel Test for Resistance to Thermal and Structural Spalling of Super Duty Fireclay Brick (C 122 - 42)

Committee C-9 on Concrete and Concrete Aggregates

An informal progress report was presented to the Executive Committee.

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[7] These recommendations were approved by Committee B-8 and accepted by Committee E-10, on August 27, 1945.

Committee C-12 on Mortars for Unit Masonry

Report presented by title.

Committee C-14 on Glass and Glass Products

The following recommendation was accepted by Committee E-10:

*Accepted as Tentative, Revision in:**

Def. of the Term Glass (C 162 – 41 T)

Committee C-15 on Manufactured Masonry Units

Report presented by title. The following recommendation was presented to Committee E-10, but action was deferred pending completion of letter ballot vote in Committee C-15:[8]

Proposed Revision in Tentative:

Spec. for Vitrified Clay Filter Block for Trickling Filters (C 159 – 41 T)

Committee C-16 on Thermal Insulating Materials

Report presented by E. T. Cope, chairman, and the following actions taken:

Adopted as Standard:

Test for Compressive Strength of Preformed Block Type Thermal Insulation (Identical with compressive strength test in Method C 165 – 41 T)
Test for Covering Capacity and Volume Change Upon Drying of Thermal Insulating Cement (C 166 – 41 T), as revised
Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (C 177 – 42 T), as revised

*Accepted as Tentative:**

Test for Flexural Strength of Preformed Block Type Thermal Insulation (Formerly part of Method C 165 – 41 T)

*Accepted as Tentative, Revisions in:**

Spec. for Mineral Wool Thermal Insulating Cement (C 195 – 44 T)

Committee D-1 on Paint, Varnish, Lacquer, and Related Products

Report presented by C. H. Rose, secretary and the following actions taken:

Adopted as Standard:

Method for Evaluating the Degree of Resistance to Blistering of Organic Coatings on Metal When Subjected to Immersion or Other Tests Involving Exposure to Moisture or Liquids (D 714 – 43 T)
Methods of Analysis of Barium Sulfate Pigments (D 715 – 43 T)
Methods of Analysis of Mica Pigment (D 716 – 43 T)
Methods of Analysis of Magnesium Silicate Pigment (D 717 – 43 T)
Methods of Analysis of Aluminum Silicate Pigment (D 718 – 43 T)
Methods of Analysis of Diatomaceous Silica Pigment (D 719 – 43 T)

Adopted as Standard, Revisions in:

Test for Coarse Particles in Pigments, Pastes, and Paints (D 185 – 37)
Spec. for Butanol (Normal Butyl Alcohol) (D 304 – 40)
Spec. for Zinc Sulfide Pigments (D 477 – 41)

Editorial Change Accepted in:

Methods of Sampling and Testing Lacquer Solvents and Diluents (D 268 – 44)[9]

The following recommendations were presented to Committee E-10, but action was deferred pending completion of letter ballot vote in Committee D-1:[10]

Proposed Tentatives:

Method of Evaluating Degree of Resistance of Traffic Paint to Abrasion, Erosion, or a Combination of Both, in Road Service Tests
Rec. Practice for Operating Light and Water Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products
Methods for Producing Films of Uniform Thickness of Paint, Varnish, Lacquer, and Related Products on Test Panels

Proposed Revisions in Tentatives:

Test for Phthalic Anhydride Content of Alkyd Resin Solutions (D 563 – 43 T)
Method of Preparation of Steel Panels for Exposure Tests of Enamels for Exterior Service (D 609 – 41 T)

Proposed Tentative Revisions of Standards:

Methods of Chemical Analysis of White Pigments (D 34 – 39)
Spec. for Lampblack (D 209 – 41)

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[8] This recommendation was approved by letter ballot of Committee C-15 and accepted by Committee E-10 on July 24, 1945.

[9] This recommendation appeared in the preprinted report as a revision of the standard for immediate adoption.

[10] These recommendations were approved by Committee D-1 and accepted by Committee E-10 on August 27, 1945.

Spec. for Bone Black (D 210 - 41)
Spec. for Pure Chrome Green (D 212 - 41)
Spec. for Prussian Blue (D 261 - 41)
Spec. for Ultramarine Blue (D 262 - 41)
Spec. for Chrome Oxide Green (D 263 - 41)
Spec. for Titanium Dioxide Pigments (D 476 - 41)
Spec. for Carbon Black (D 561 - 41)
Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 - 44)

The recommendation for adoption as standard of the Tentative Specifications for Oiticica Oil (Permanently Liquid) (D 601 - 41 T) which appeared in the preprinted report was withdrawn by the Committee.

Committee D-2 on Petroleum Products and Lubricants

Report presented by T. A. Boyd, chairman, and the following actions taken:

Adopted as Standard, Revisions in:

Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products (D 86 - 40)
Test for Flash and Fire Points by Means of Open Cup (D 92 - 33)
Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 - 44)
Test for Knock Characteristics of Motor Fuels (D 357 - 44)
Test for Carbonizable Substances in White Mineral Oil (Liquid Petrolatum) (D 565 - 43)
Test for Carbonizable Substances in Paraffin Wax (D 612 - 43)

Accepted for Publication as Information Only:

Proposed Method of Test for Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants
Proposed Method of Test for Total Olefinic and Aromatic Hydrocarbons in Gasoline

*Accepted as Tentative:**

Method of Analysis of Petroleum Sulfonates

*Accepted as Tentative, Revisions in:**

Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter (D 155 - 39 T)

A report of Technical Committee A on Gasoline, containing proposed revisions in the requirements for the exhaust system in the C.F.R. engine in Section A10 of the Standard Method of Test for Knock Characteristics of Motor Fuels (D 357 - 44) and in the Tentative Method of Test for Knock Characteristics of Aviation Fuels (D 614 - 44 T), and also a change in the requirements for mixture heater assembly in Section A5 of Method D 357, was accepted for publication as an appendix to the Report of Committee D-2.

Committee D-3 on Gaseous Fuels

Report presented by title.

Committee D-5 on Coal and Coke

Report presented by the chair, and the following actions taken:

Adopted as Standard:

Method of Tumbler Test for Coal (D 441 - 37 T), as revised

*Accepted as Tentative, Revisions in:**

Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 44)

Committee D-6 on Paper and Paper Products

Report presented by G. H. Harnden, secretary, and the following actions taken:

Adopted as Standard:

Method of Turpentine Test for Grease Resistance of Paper (D 722 - 43 T)
Test for Degree of Staining of Paper by Alkali (D 723 - 43 T)
Test for Surface Wettability of Paper (Angle-of-Contact Method) (D 724 - 43 T)
Test for Wire and Felt Sides of Paper (D 725 - 43 T)
Test for Kerosine Number of Roofing and Flooring Felt by the Vacuum Method (D 727 - 43 T)

Accepted for Publication as Information Only:

Proposed Methods of Test for Smoothness of Paper

*Accepted as Tentative:**

Test for Ply Adhesion of Paper or Vulcanized Fibre
Test for Absorption by Bibulous Papers of Water and Writing Ink
Test for Degree of Wet Curl of Paper
Test for Water Vapor Permeability of Sheet Materials at Elevated Temperature and Humidity
Test for Edge Tearing Strength of Paper
Test for Tensile Breaking Strength of Paper and Paper Products
Test for Wet Tensile Breaking Strength of Paper and Paper Products

Committee D-7 on Wood

Report, including the paper on "Methods Used for the Measurement of the Moisture

Content of Wood" prepared by M. E. Dunlap, was presented by L. J. Markwardt, Secretary.

It was announced that the proposed revisions appearing in the preprinted report in the Standard Definitions of Terms Relating to Timber (D 9 – 30) had been withdrawn by the committee.

The following recommendation was presented to Committee E-10, but action was deferred pending completion of letter ballot vote in Committee D-7:[11]

Proposed Revision in Tentative:

Methods of Testing Plywood, Veneer, and Other Wood and Wood-Base Materials (D 805 – 44 T)

Committee D-9 on Electrical Insulating Materials

Report presented by W. A. Zinzow, secretary, and the following actions taken:

Adopted as Standard, Revisions in:

Test for Insulation Resistance of Electrical Insulating Materials (D 257 – 38)
Methods of Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 43)

Accepted for Publication as Information Only:

Proposed Methods of Testing Askarels

*Accepted as Tentative:**

Test for Gas Content of Insulating Oils

*Accepted as Tentative, Revisions in:**

Methods of Testing Molded Materials Used for Electrical Insulation (D 48 – 43 T)
Methods of Testing Electrical Insulating Oils (D 117 – 43)
Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 44 T)
Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 44 T)
Spec. for Flexible Treated Cotton and Rayon Sleeving Used in Electrical Insulation (D 372 – 44 T)
Methods for Conditioning and Classifying for Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 44T), jointly with Committee D-20 on Plastics
Spec. for Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 – 43 T)
Method of Flexural Test of Plastics (D 790 – 44 T)

It was announced that the proposed revisions appearing in the preprinted report in the Tentative Method of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 – 44 T) had been withdrawn by the committee.

Committee D-10 on Shipping Containers

Report presented by title.

Committee D-11 on Rubber and Rubber-Like Materials

Report presented by the chair and the following actions taken:

Adopted as Standard, Revisions in:

Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (D 573 – 42)

*Accepted as Tentative:**

Spec. for Natural Rubber Cups for Use in Hydraulic Actuating Cylinders
Rec. Practice for Conditioning of Rubber and Plastic Materials for Low-Temperature Testing
Methods of Identification and Quantitative Analysis of Synthetic Elastomers

Committee D-12 on Soaps and Other Detergents

Report presented by the chair and the following actions taken:

Adopted as Standard:

Test for Water-Immiscible Organic Solvents Volatile with Steam in Sulfonated and Sulfated Oils (D 500 – 43 T)
Spec. for Tetrasodium Pyrophosphate (Anhydrous) (D 595 – 44 T)
Spec. for Liquid Toilet Soap (D 799 – 44 T)
Methods of Chemical Analysis of Industrial Metal Cleaning Compositions (D 800 – 44 T)

Committee D-13 on Textile Materials

Report presented by H. J. Ball, chairman, and the following actions taken:

Adopted as Standard:

Def. of Terms Relating to Textile Materials (D 123 – 44 T), comprising definitions of three terms revised to read as follows:

Turn, n. Rope.—The distance parallel to the axis of a rope in which a strand makes one complete spiral.

Yarn, Cross-Blended, n.—A single yarn spun from a blend or mixture of different fiber species.

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[11] This recommendation was approved by Committee D-7 and accepted by Committee E-10 on August 14, 1945.

EXAMPLE.—A yarn spun from cotton fibers and rayon staple, or from wool fibers and acetate staple, or from wool and cotton fibers.

Yarn, Self-Blended, n.—A single yarn spun from a blend or mixture of the same fiber species.

EXAMPLE.—A spun rayon yarn produced from staple of different lengths or different deniers.

Adopted as Standard, Revisions in:

Spec. for Textile Testing Machines (D 76–42)
Methods of Testing Wool Felt (D 461–44)

It was announced that Committee D-13 would present a number of recommendations on tentatives to the Society through Committee E-10 subsequent to the annual meeting.

Committee D-14 on Adhesives

Report presented by title.

Committee D-16 on Industrial Aromatic Hydrocarbons

Report presented by title, and the following actions taken:

*Accepted as Tentative:**

Spec. for Nitration Grade Benzene
Spec. for Industrial Grade Benzene
Spec. for Nitration Grade Toluene
Spec. for Industrial Grade Toluene[12]
Spec. for Nitration Grade Xylene
Spec. for Five-Degree Xylene
Spec. for Ten-Degree Xylene
Spec. for Industrial Grade Xylene[12]
Spec. for Industrial 90 Benzene[12]
Spec. for Refined Solvent Naphtha
Spec. for Crude Light Solvent Naphtha
Spec. for Crude Heavy Solvent Naphtha
Test for Specific Gravity, Color, and Hydrogen Sulfide and Sulfur Dioxide Content (Qualitative) of Industrial Aromatic Hydrocarbons
Test for Acid Wash Color of Benzene, Tolune, Xylenes, and Similar Industrial Aromatic Hydrocarbons
Test for Acidity of Benzene, Toluene, Xylenes, and Similar Industrial Aromatic Hydrocarbons
Test for Solidifying Point of Benzene
Test for Paraffins in Industrial Aromatic Hydrocarbons
Method of Copper Corrosion Test of Industrial Aromatic Hydrocarbons
Test for Distillation of Industrial Aromatic Hydrocarbons

Committee D-17 on Naval Stores

Report presented by C. P. Chapman, and the following actions taken:

Adopted as Standard:

Methods of Sampling and Grading Rosin (D 509 – 44 T)

The following recommendations were presented to Committee E-10, but action was deferred pending completion of letter ballot vote in Committee D-17:[13]

Proposed Tentatives:

Test for Acid Number of Dark Rosin
Methods of Sampling and Testing Pine Tars and Pine-Tar Oils

Proposed Revisions in Tentative:

Def. of Terms Relating to Tall Oil (D 804 – 44 T)

Committee D-18 on Soils for Engineering Purposes

Report presented by the chair and the following actions taken:

Adopted as Standard:

Methods of Surveying and Sampling Soils for Highway Subgrades (D 420 – 42 T)

*Accepted as Tentative:**

Test for Specific Gravity of Soils

Committee D-19 on Water for Industrial Uses

Report presented by title. The following recommendations appearing in the report as preprinted will be presented to Committee E-10 upon completion of the letter ballot vote in Committee D-19:[14]

Proposed Tentatives:

Test for Total Aluminum and Aluminum Ion in Industrial Waters
Test for Manganese in Industrial Waters
Test for Dissolved Oxygen in Industrial Waters
Test for Silica in Industrial Waters
Rec. Practice for Sampling Water from Stationary Boilers

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[12] These specifications were accepted subject to appropriate changes in titles of related specifications under the jurisdiction of Committee D-1.

[13] These recommendations were approved by Committee D-17 and accepted by Committee E-10 on August 1, 1945.

[14] These recommendations were approved by Committee D-19 and accepted by Committee E-10, on August 27, 1945, except the Method for Dissolved Oxygen which was accepted for publication as information, see p. 360.

Committee D-20 on Plastics

Report presented by Robert Burns, chairman, and the following actions taken:

Adopted as Standard:

Descriptive Nomenclature of Objects Made from Plastics (D 675 – 43 T)

*Accepted as Tentative:**

Test for Ammonia in Phenol-Formaldehyde Molded Materials

*Accepted as Tentative, Revisions in:**

Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 – 43 T), subject to concurrance by Committee D-9[15]
Methods of Conditioning and Classifying for Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 44 T), jointly with Committee D-9
Test for Haze of Transparent Plastics by Photoelectric Cell (D 672 – 44 T)
Spec. for Cellulose Acetate Plastic Sheets (D 786 – 44 T)
Rec. Practice for Molding Specimens of Phenolic Materials (D 796 – 44 T)

It was announced that the recommendation for adoption as standard of the Tentative Method of Test for Water Vapor Permeability of Plastic Sheets (D 697 – 42 T) appearing in the preprinted report had been withdrawn by the committee.

Committee E-3 on Chemical Analysis of Metals

Report[4] presented from manuscript by G. E. F. Lundell, chairman, and the following actions taken:

Adopted as Standard:

Method of Chemical Analysis for Selenium in Steel (E 30 – 43 T)
Methods of Chemical Analysis of Aluminum and Aluminum Alloys (E 34 – 42 T), as revised
Methods of Chemical Analysis of Magnesium and Magnesium Alloys (E 35 – 42 T)
Methods of Chemical Analysis of Brasses (E 36 – 42 T)
Methods of Chemical Analysis of Pig Lead (E 37 – 42 T)
Methods of Chemical Analysis of Nickel (E 39 – 42 T)
Methods of Chemical Analysis of Slab Zinc (Spelter) (E 40 – 42 T)
Methods of Chemical Analysis of Zinc-Base Die-Casting Alloys (E 47 – 42 T)
Methods of Chemical Analysis of Silver Solders (B 81 – 36 T)

Adopted as Standard, Revisions in:

Methods of Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron (E 30 – 42)

Committee E-10 on Standards

This report, presented by H. S. Vassar, chairman, recorded the large number of recommendations accepted during the year by Committee E-10 on behalf of the Society. Mr. Vassar referred to the number of recommendations affecting tentatives accepted by Committee E-10 on behalf of the Society at the meeting held in the morning prior to the Annual Meeting. For convenience of reference these recommendations are listed above under the respective committees which made the submittals. This report also covered the work of the committee in the promotion and expansion of A.S.T.M. standardization activities, announcing the organization during the year of an administrative committee on ultimate consumer goods and considerations being given to undertaking work on sulfur cements, leather, and asbestos cement products. The report also referred to the fact that Committee E-10 will give consideration to proposals relating to participation by A.S.T.M. in standardization activities initiated under the auspices of the United Nations Standards Coordinating Committee.

Election of Officers:

President Bates then called upon the Secretary-Treasurer to report the results of the letter ballot on election of officers. Of the 1940 ballots cast, the results were as follows:

For President, to serve for one year:
J. R. Townsend, 1940 votes.
For Vice-President, to serve for two years:
T. A. Boyd, 1940 votes.

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[15] This revision was subsequently withdrawn on the recommendation of Committee D-9.

For members of the Executive Committee, to serve for two years:
J. R. Freeman, Jr., 1940 votes.
L. J. Markwardt, 1940 votes.
C. H. Rose, 1940 votes.
L. P. Spalding, 1940 votes.
W. A. Zinzow, 1939 votes.

In announcing the election of the above officers, President Bates said that the new officers would be presented at the dinner meeting arranged by the New York District Committee to be held that evening.

Committees Not Reporting:

The preliminary program for the Annual Meeting contemplated reports from the following committees, but these committees did not present reports to the Society this year:

Committee A-3 on Cast Iron
Committee B-9 on Metal Powders and Metal Powder Products
Committee D-4 on Road and Paving Materials
Committee D-8 on Bituminous Waterproofing and Roofing Materials
Committee E-1 on Methods of Testing
Committee E-2 on Spectrographic Analysis
Committee E-4 on Metallography
Committee E-7 on Radiographic Testing

In adjourning the Forty-eighth Annual Meeting, *sine die*, President Bates announced that the meeting would be followed by a dinner in the evening sponsored by the New York District Committee at which the presidential address would be presented, the newly elected officers of the Society introduced, and a very timely talk given on the work of the Naval Construction Battalions (Seabees).

Presidential Address:

The presidential address of President P. H. Bates on the subject "Preparation for the Future"[16] was presented at the dinner meeting sponsored by the New York District Committee.

Address by Admiral Lewis B. Combs:

At the conclusion of the presidential address a very interesting illustrated talk on "Preparing the Way for Victory with the Seabees"[17] was presented by Rear Admiral Lewis B. Combs, (CEC) USN.

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[16] See p. 14.
[17] An extended abstract of this address was published in the ASTM BULLETIN, No. 135, August, 1945, p. 17.

TECHNICAL PAPERS

The following papers were preprinted in advance of the Annual Meeting and distributed to those members who had requested copies:

Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr.
The Effect of Overstress in Fatigue on the Endurance Life of Steel—J. B. Kommers.
A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere—H. R. Copson.
Practical Electric Resistance Strain Gage Procedures for Structural Tests on Ships—W. V. Bassett (Printed in May, ASTM BULLETIN).
Single-Strip Compression Test for Sheet Materials—Harry LaTour and Don S. Wolford.
Observations on the Appearance Welding of Malleable Castings—H. A. Schwartz, Ira Young, and James Hedberg.
The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid—David J. Mack.
Fracture Testing of Alloy Steels for Aircraft Engine Forgings—R. D. Haworth, Jr., and A. F. Christian. (Special preprint distribution early in May.)
The Effect of the Iron Content of Cupro-Nickel on Its Corrosion Resistance in "Sea Water"—A. W. Tracy and R. L. Hungerford. (Special preprint distribution early in May.)
The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer. (Special preprint distribution early in May.)
Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-

Lime Mortars—G. J. Fink and Emil Trattner. (Special preprint distribution early in May.)

Stress Conditions for the Failure of Saturated Concrete and Rock—K. Terzaghi.

Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders —Gerald Pickett.

Test Criterion for an Incombustible Material—N. P. Setchkin and S. H. Ingberg.

Automatic Accelerated Freezing-and-Thawing Apparatus for Concrete—Charles E. Wuerpel and Herbert K. Cook.

Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete—Bryant Mather.

Dimensional Stability of Plastics—Robert Burns (Printed in May, ASTM BULLETIN).

Effect of Length on the Strength of Compression Test Specimens—J. Tucker, Jr.

In addition, the following Annual Meeting papers will be printed and distributed when available:

A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel—H. F. Moore.

The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C.—D. J. McAdam, Jr., G. W. Geil, and R. W. Mebs.

A Sulfur Print Method for the Study of Crack Growth in the Corrosion-Fatigue of Metals—R. C. Brumfield.

Cast-to-Size Impact Specimens for Aluminum Sand Casting Alloys—R. A. Quadt (August, ASTM BULLETIN).

Compression Testing of Magnesium Alloy Sheet—A. A. Moore and John C. McDonald (August, ASTM BULLETIN).

The Calculation of Electrical Contacts. Under Ideal Conditions—Erle I. Shobert, II.

A Method of Particle Size Determination of Soils, Cements, etc., by Means of a Chainomatic Specific Gravity Balance—Eugene V. Barrett.

The Effect of Repeated Loading on the Bond Strength of Concrete—C. W. Muhlenbruch.

A Comparison of Absorption and Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt.

A Simplified Method for the Determination of the Specific Gravity of Wood and Plastics—E. George Stern and Paul S. Dear (August, ASTM BULLETIN).

Some Factors in the Interpretation of Small-Scale Tests for Fire-Retardant Wood—F. W. Gottschalk (October, ASTM BULLETIN).

Fatigue Tests of a Laminated Mitscherlich-Paper Plastic—W. N. Findley.

A New Coating Thickness Gage—Samuel Lipson (August, ASTM BULLETIN).

The Evaluation of Surface-Active Agents—Jay C. Harris.

Effect of Dimensions of Specimens Upon the Precision of Strength Data—John Tucker, Jr.

The Maximum Stresses Present on the Failure of Specimens of Brittle Materials—John Tucker, Jr.

The following papers which had been listed in the preliminary program for the Annual Meeting were subsequently withdrawn:

Behavior of Concrete Under Sustained Loads Near the Ultimate—W. H. Price and R. C. Zimmerman.

The Influence of Gypsum on the Hydration and Properties of Portland Cement Pastes—William Lerch.

Symposium on Adhesives—It is proposed to hold this symposium at a later date and it is planned to preprint the papers for this symposium when available.

PREPARATIONS FOR THE FUTURE OF THE A.S.T.M.

Annual Address by the President

P. H. Bates[1]

June 27, 1945

This annual meeting of our Society is different in practically every respect from any that have been held before. In this very much abbreviated meeting it is desirable that the Presidential Address should also be brief. As it is essentially a business meeting with a minimum of technical discussions, it is befitting that the address be nontechnical. Also, as all of us under the present world conditions are in an uncertain and unusual transitional period, it would seem desirable that we give our attention to what we as a Society are now doing and have been doing in the immediate past that will affect our activities in the immediate future.

It might be said that what could be presented under such a topic would in a sense be the report of the Special Study Committee. (The final report of this committee is now being prepared for submission to the Executive Committee.) This is correct and what I shall say here will largely be somewhat of a discussion of some phases of its findings and remarks regarding their application. This committee was appointed about two years ago to review in a broad manner how the Society was organized, how it is now pursuing its technical work and how it was presenting the results of such work to the public. Having noted these and also having compared these with what other societies were doing, it was to decide whether these were being carried out in an efficient, effective manner. If such was the case, did the future indicate that changes should be made? Lastly, and particularly, should the Society expand into new fields?

The Study Committee has done a thorough, painstaking, excellent piece of work. Its recommendations when put into effect, as they are rapidly being done, will surely result in all that was and could be hoped for. These recommendations are those of a committee and not of an individual. As such they represent the consensus of opinion of a group. Consequently, they are neither extremely radical nor extremely conservative—they are just about in the center, despite the fact that to some the committee has gone too far. To others it has not gone far enough. To me, personally, it has gone a little to the right of the center, while, as you might infer, I would have preferred it to have wandered a little to the left.

I am for a thoroughly aggressive Society—one that might be accused of committing sins of commission rather than sins of omission. If there is doubt as to whether something should or should not be done, then surely do it. This should be borne in mind as we proceed in this discussion.

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[1] Chief, Clay and Silicate Products Div., National Bureau of Standards, Washington, D. C.

That we have an aggressive Society is shown, first, by the fact that it has attained through its up-to-date and high-quality work, preeminence in this country in the field of preparing Standard Specifications and Standard Test Methods. It is recognized here and abroad as the outstanding organization in this field not only in the United States but in the world. Second, by its extending its activities in two fields—Simulated Service Testing including tests on parts and assemblies, and Ultimate Consumer Standards—both of which are so large and so urgently requiring work of the type for which no group is so well fitted as ours.

Our work in these two new fields—new at least so far as our Society is concerned, but otherwise far from new—should very materially expand the Society's contacts. These are indeed very large fields. To date many of those interested in them have not been in close contact with our work. Hence, we must secure the advice and assistance of what might be called strangers to our present procedures. Also entering into new fields we must study them carefully and see how we can apply our usual methods or how they must be modified. From noting what confronts us, it can readily be seen that we are undertaking work which must be entered upon with careful preliminary thought.

I am sure others than myself have frequently wondered why there has been such a lack of activities in these fields. Surely there have always been ultimate consumers. Yet today there are so few ultimate consumer standards that it can be said there are none. Is not this due to the fact that in this case the consumer is the ultimate user—in other words, an individual? And an individual as such, in such work, even though he may be a rugged individual, generally makes very slow and very little progress as long as he acts as an individual. But when he unites with others and becomes an organization working to attain certain results, very likely rapid progress is made. In recent years a number of organizations of ultimate consumers have arisen and they are making progress. Practically all of them will welcome contact with our Society and work with it in securing the needed standards.

Testing of Assemblies also is not new. I had entered upon my life's work (which has always been directly connected with research in developing standard specifications and standard testing methods and their application) but one year when I was detailed to take part in a series of tests of assemblies which lasted for a year. I had the pleasure of being connected with the Pennsylvania Railroad locomotive testing plant when it was first erected and used at the St. Louis Exposition in 1904. A locomotive is surely an assembly though it might be said that a test of that kind—in general determining the efficiency of a boiler and of a reciprocating engine—is not the kind now contemplated. But it must be said that there were many test procedures used in that work for which our Society now has or will have standard methods, which it did not have at that time due to its recent organization.

It seems certain that through the development of testing procedures for many assemblies—but particularly in bridges, buildings, etc.—we can learn to design them more properly. The airplane designers have been forced to realize, more through efficiency and economy than through engineering that overdesign is just as bad and far more wasteful than underdesign. A certain member of a bridge or any other structure should not be overdesigned just because it is not known with sufficient assurance, through lack of adequate tests or test methods, how it is stressed by adjoining members. The proper development of our contemplated work in Tests of Assemblies should lead to a more intelligent and correct use of and in time the elimination of "factors of safety." At least it is hoped that they will no longer be referred to as "factors of ignorance"—as they now are so aptly characterized.

I am inclined to believe that the A.S.T.M. had not entered this field of assembly testing for two reasons: first, because it was extremely busy in its old established work (this does not hold too much weight with me); secondly, we have been too much restricted in our endeavors by a too narrow interpretation of the words of our charter, "materials of engineering." It is, of course, needful to have a delineation of our field. In general, "materials of engineering" accomplishes that purpose. But when we are in doubt as to whether activities in a certain direction would come within such limits, let us decide that they do and proceed accordingly. Remember our headquarters are in Philadelphia and it is certain that one would not need to go many blocks from our offices there before we could find one of the noted breed of "Philadelphia lawyers" who could well justify almost any work in any field as being wholly concerned with "materials of engineering."

So much for these two new efforts. They are getting under way most auspiciously and it is certain that though careful handling and development must be followed, which at first may seem to show annoyingly slow progress, in due time the hoped-for and required advancements will be made and the Society will be recognized as a leader in these fields.

Our publication policies and program have been a matter of considerable thought on the part of the Publication, Study, and Executive Committees. You can be assured that much thought is still needed. The interests of the A.S.T.M., like those of many other technical societies, are centered in developing and systemizing knowledge (in our case largely the art of testing and its application) and in the broadcasting of this knowledge through publications. In other words, we are publishers. The success of such societies is measured quite accurately by the amount of and broad acceptance of this printed matter. Our success is indicated by the fact that the income from this source now exceeds that from membership dues. Such a fact shows that this feature of our efforts must be a matter of much concern at all times.

But certain specific features in connection with our publications have given concern. The size of our

Proceedings and Books of Standards and the question of promptness of presenting all material to be released forced a study of how and how often this printed matter should be issued.

The recent deliberations have resulted in one new very desirable procedure, namely, the immediate printing, following acceptance, of all technical papers. This is indeed an excellent step. But there is still before us, unsettled, the size of the *Proceedings* and the Books of Standards. Can the former be reduced by briefing committee reports or by publishing these and more of the technical papers in the BULLETIN, even though this might lead to its more frequent issuing? Can the Books of Standards be reduced by presenting Standard Specifications in one volume and Standard Methods in another? Or why not issue each specification or method separately instead of in book form? This is now being done by some other standardizing groups. Should not the Society have a monthly issue of some kind—as, for instance, a monthly issue of the BULLETIN? These and other questions regarding printing have been extensively discussed and will be more so in the future. Our publication affairs are not upon a truly satisfactory nor final basis.

Before the matter of publications is entirely laid aside, it might be well to give a few minutes to thinking of our meetings, from which come so much of our material for printing. Aside from the question of the desirability of having two meetings so closely together, as the "Spring" and the "Annual" Meetings, have not the meetings developed so that too little time is devoted to technical papers? To me, as somewhat of an "old timer," it seems that in the "good old days" of the past there were relatively more papers and discussions than at the present time. Through technical papers on the various broad phases of testing and the development of test methods and specifications so much of such vital concern to such activities is brought forward that we can hardly do too much to foster them. The custom of holding one or more sessions at the Spring Meeting featuring a symposium on some subject is most excellent. It would be well to have more sessions at the Annual Meeting when papers alone would be presented.

I cannot leave the subject of meetings without a few words regarding exhibits. I wish these could be held more frequently despite the fact that even now without these some of the members have a very full week at the Annual Meeting. But aside from possible financial return to the exhibitor, there are always many returns to the viewer and the membership of the Society is largely in this class. But in all exhibits more effort should be made to have groups and individuals—not commercial producers of equipment or apparatus—present examples of their own efforts. In the course of a couple of years well worthwhile new examples of such developments would be available of much interest and benefit to a large number.

Here I would have ended my discussion of our meetings had there not come to hand a copy of a talk, "Science Is Not Magic," by Dr. R. C. Hockett, Scientific Director of the Sugar Research Foundation, Inc. As a text for his talk he used the seventh and eighth verses of Genesis XI. Maybe you will recall that there we have the story of the Tower of Babel—how the Lord broke up a very well-organized co-operative effort (just such as ours is) by a much more effective one of confounding their language so that they did not "speak one another's language."

Everywhere in technical societies we have through almost excessive specialization such a development of "tongues," that as Dr. Hockett says, "at the present time workers in the various branches and divisions of science do not understand each other any too readily and the layman finds the language of all of these quite incomprehensible."

We have had in recent years groups splitting off from others or being newly formed solely because of specialization which led the new group to believe it had nothing in common with the old or any other one. Another new tongue had been born. Committee X-13 of the A.S.T.M. is concerned with a commodity and test methods which in the minds of its members are unique and have nothing in common with the commodities and procedures which concern all the other committees. Hence, it maintains a marked aloofness from and associates but slightly with the full activities of the Society. This should be remedied and can be done by getting even the most distantly related committees to understand one another and seeing what they have in common.

The gist of Dr. Hockett's talk was in presenting the role of the "scientific commentator"—the individual who translates the technical jargon of the specialist into the "language of the street" of the layman. Bear in mind the specialist in any one field is the layman in others. I hope that those placed in the Headquarters Staff as contacts for the several groups of committees will develop into true commentators, who will be able to translate the work of the committees in their group so that the other groups will not only understand what is being done but also why, and to the extent that there will be more frequent intercommittee interest, contacts, and such.

Finally, it would be well if each of these or a Headquarters Editor could prepare prefaces of all papers which would tell all laymen the why and wherefore of the paper and let their fancies run wild as to its possible broad and future application. A paper on determining particle size by air permeability was just a title to 95 per cent of the readers of the Society's BULLETIN. Why the interest in particle size? Who is interested? Who might and will be interested? A good scientific commentator could have written a preface which would have caused the paper to have been read by at least a very large minority of the BULLETIN'S readers. Particle size is of concern to the metals group (powder metallurgy, size of abrasives for finishing metals, etc.), to practically all of the committees in the C group, and in the D group remember the importance of pigment grain size, the use of sized inorganic fillers in tars and asphaltums, the use of clay, fuller's earth, talc, etc., whose particle size is so important in the paper, textile, and petroleum industries.

May I close this dissertation on technical commentators to correlate the committee work with the

Society so that there may be a more intimate contact and a better understanding between committees and more of an appreciation of each other's work by a "lastly" text (also used by Dr. Hockett)—

> "And the Lord said, 'Behold, the people is one, and they have one language—and now nothing will be restrained from them which they have imagined to do?"—Genesis XI: 6.

One of our Society's policies and procedures is, I am sure, provocative of more discussion in the technical committees and in the Executive Committee than all the others combined. Reference is made to the balance of membership of committees as between producers and other interests, the requirements as to the "interest" of committee chairmen and to a less degree the classification of interest for voting purposes of technical committee membership. This has doubtlessly received its usual amount of annual discussion by all concerned during the past year, plus a considerable amount on the part of the Study Committee. After all has been "said and done," the restrictions are just about where they were before the year started and before quite a few previous years started. To my mind, this shows progress—strange as it may seem. It shows that our founders and early organizers did quite well and through the years, despite most frequent extended discussions, we are continuing by confirming their wisdom.

Practically all technical committees are faced with the difficult task of securing adequate interest both as to numbers and activity on the part of the consumer and general interests. But when the field has been well canvassed, the desired results are invariably obtained. If one could measure the "intensity" of the interest applied by the producer, consumer, and general interests, it is quite certain that even with the presently demanded less number of producers, we would find the "intensity" of the producer far exceeding the "intensity" of the two other groups. This cannot be changed though the numerical balance might. But it is hoped this latter will never be done. I feel that if it were, the high regard and esteem of the Society's Standards would be most materially lowered.

It has been my pleasure to have attended meetings of six of our District Committees during the past 14 months. Even though in a few cases the attendance was rather small, the small and the large meetings, as well as those very largely attended, evidenced sufficient interest and enthusiasm to indicate that the idea of having these sectional groups is excellent. Despite the fact that in all of our large cities one can readily find more meetings of technical societies than one can find time to attend, it is still true that those with something worth while to offer can and do draw good-sized audiences. I believe that all of the District Committees, with assistance from the Society's Headquarters Staff, which will always be promptly and heartily given, could have two meetings yearly with such attractive programs that large audiences would result. Testing and its ramifications are so broad that well-timed discussions of one of its many phases will bring many together. Such meetings will very materially enhance the prestige of the Society and expand its membership. These District Committees should by all means be fostered and further developed in some cases. This is now under way by a new Administrative Committee which is certain to give a good account of itself.

A reorganization and extension of the Society's Headquarters Staff has been authorized and is now being effected. One feature of this is particularly commended and should have your interest and support. Reference is made to the assigning of a member of the staff to keep in contact with each group of technical committees. There will ultimately be a member of the staff following the work of each group of committees; attending the meetings of each committee, keeping these especially informed of the work of the other committees in the group and maintaining a direct helpful contact between headquarters and committee members. These staff members will in no manner dictate to committee officers or interfere with their work. These latter will act with their past customary freedom. This feature of headquarters organization is intended to coordinate the work of the committees and the Society and to have both reflect the thoughts and demands of the public. It is certain to result in a more unified acting Society.

You all know by this time that our Society will during the coming year enjoy for the first time in its history its own home. It has surely been most fortunate in securing this—so favorably located in the heart of Philadelphia on a notable thoroughfare, which with time will surely be enhanced with further beauty, and on a site so strikingly surrounded with literary and technical organizations. Since the Executive Committee decided that the Headquarters should be in an urban rather than suburban area, it is hard to conceive of a more favorable location, to say nothing of the remarkably low cost of acquisition.

All of us hope that in a relatively brief time we shall be in the postwar era. This review of the developments in the Society during the past year—so many of which evolved from a consideration of how the Society should conduct its affairs after the war—I hope will clearly show you that it will be organized and ready to meet the demands of that era. Well settled in its new home with its staff organized according to the new setup and working smoothly as a result of the presently coming practice period, we can be assured that the A.S.T.M. will carry on even more effectively and efficiently than it has in the past, with not only a loyal hard-working staff at Headquarters, but with an equally loyal and hard-working membership.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE*

With our Nation in the fourth year of war, the Executive Committee reports to the Society membership on the activities of a year replete with many important and far-reaching accomplishments in both technical and administrative fields. So long as we are at war, the prime objective of everyone is and must be the winning of that war; and until the war is won the Society will continue to give priority and first emphasis to all activities that will in any way assist the Government and industry in carrying on the war effort. Our most important contribution, of course, is with respect to the development of tests and specifications for materials and in the carrying on of investigation on the properties of materials. Emphasis has accordingly been placed on such work during the past year, although it will be obvious that with the improved condition of supply of critical and strategic materials and the attainment of full war production there has not been as much need for development of emergency methods and specifications as existed during the first years of the war.

Nevertheless, the emergency standardization procedure has been used effectively by many of the standing committees. During the year there were accepted and published ten new emergency alternate provisions and four new emergency standards, and 17 emergency alternate provisions were revised. A number of emergency standards were considered suitable for acceptance as tentative and 14 were transferred to that status. With the relaxation of many materials and production controls, it has been found that a number of emergency alternate provisions are no longer needed and during the year 34 such provisions and one emergency standard were discontinued, although many of the emergency alternate provisions were used as the basis for the revision of the standard to which they formerly applied. As a result there are now on the books of the Society 97 emergency alternate provisions and 26 emergency standards, a total of 123 compared to approximately 155 such items a year ago.

It can appropriately be mentioned at this point that as a matter of policy it is intended that all emergency alternates and emergency standards should be transferred as promptly as possible either to standard or tentative status or be dropped, and that further development of emergency requirements is to be discouraged unless they are truly needed to meet a war emergency. To guard against retention of such emergency provisions beyond the period of their usefulness, it is now required that in order to be retained they must be annually reaffirmed by ballot of the promulgating group and approved by the Committee on Standards.

Included in the emergency specification work of direct significance to the war effort might be mentioned: tests for aromatics in aviation gasoline developed for and with the cooperation of the Air Corps; tests for inorganic elements in lubricating oils; cloud and pour tests of petroleum products at temperatures down to −100 F., prepared for the Air Corps from operating experiences at high altitudes and in frigid climates;

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* Presented at the Forty-eighth Annual Meeting of the Society, June 27, 1945.

friction tape specifications providing a better quality resulting from new techniques; flame test for insulated wire and cable; further modification of solder metal compositions in line with current WPB limitation orders; and four new specifications for stainless steel tubing for refinery service and general applications.

Other technical activities of either direct or indirect value to war production, offered in the form of new tentative specifications or methods during the year, include the following: two magnetic particle test methods for steel castings and heavy steel forgings; specifications for gray iron castings for pressure-containing parts for temperatures up to 650 F.; extensive revisions of the salt spray test widely used in the evaluation of war materials; extensive revisions of copper and copper alloy specifications; specifications for chromium-nickel-iron alloy castings for high-temperature service; specifications for synthetic rubber (GR-S) sheath compound for electrical cords; test for hydrogen permeability of rubber-coated fabrics widely used for such products as balloons, pontons, etc.; test for permeability of synthetic elastomers to volatile liquids; revision of specifications for cellular rubbers and hard rubber; test methods for adhesives urgently needed by the Armed Services; various types of tests for fiberboard shipping containers; specifications for shellac for electrical insulation; many new specifications and test methods for plastics; tests for plywood; and methods of test for important items of naval stores.

In the current committee reports will be found the results of much intensive work by the committees, usually in active cooperation with the Government agencies and carried out under increasingly difficult conditions occasioned by the restrictions on travel and large meetings. Among some of the more important accomplishments relating to war materials are the following: new specifications for copper-silicon and copper-silicon-zinc alloy sand castings, and for beryllium copper strip, wire, rods and bars; new methods (published as information only) for olefinic and aromatic hydrocarbons in gasoline and for pour point in lubricants containing pour point depressant; seven new test methods and 12 specifications for various industrial aromatic hydrocarbons; tests for identification and analysis of synthetic elastomers urgently needed for use with the new synthetic rubbers; specifications for natural rubber brake cups, prepared jointly by SAE and ASTM at the request of the Ordnance Department, U.S.A.; a recommended practice for conditioning rubber and plastics for low-temperature testing; and revised specifications for arc-welding electrodes.

The Society has continued to cooperate with a number of the Federal Specifications committees and with the various bureaus of the War and Navy Departments, the War Production Board and other Governmental agencies—indeed, cooperation with these agencies has been involved in many of the projects cited in the preceding paragraphs. One project that for several years engaged the close attention of Committee A-1 on Steel, namely, the National Emergency Steel Specification project of WPB, is about completed, inasmuch as the steel supply situation has improved to the point where practically all of the restrictions imposed by WPB Limitation Order L-211 have been removed. It is understood that the project may shortly be formally terminated, and it is the hope of the Executive Committee that the valuable cooperative relations that were established by the sponsors of that project may be continued in some suitable manner.

One of the outstanding contributions to the war effort has been, of course, the publication of the new and revised 1944 edition of the Book of Standards, comprising 795 standards and 440 tentatives in addition to nearly all of the emergency alternate provisions and standards previously mentioned. Unavoidable delays in the printing establishment, coupled with the tremendous volume of the publication (over 6000 pages), delayed the appearance of the last of the three parts until late in April. However, all accumulated orders of industrial and Governmental agencies have been filled and distribution to the entire membership has been completed.

While the effective functioning of the Society in relation to the war has been of prime importance, the Executive Committee has also been giving most careful thought to the future development of the Society. It is clear that our country faces a period of tremendous technological expansion—a period that will bring with it many new and modified materials and new applications of older materials. The inevitable competition between materials will place greater value than ever upon adequate tests for evaluating properties, including increased emphasis on performance testing and testing of parts and assemblies. Specifications will need to be frequently revised to keep abreast of technical developments and many new specifications will be required. Knowledge of the properties of all types of materials will be at a greater premium than ever, calling for more research and investigation on the part of our committees than probably at any time in our history. Clearly, therefore, the Society must be organized on the soundest possible basis to meet the future and to render the most effective service. In the next few sections of this report the Executive Committee discusses a number of decisions that have been made and new work undertaken to prepare the Society for the years that lie ahead. Possibly in no year in the Society's history have there been more important developments, both technically and administratively, than are here reported.

Before presenting these matters, a word about a policy for the period of transition between war and peace is appropriate. The Executive Committee realizes that this transition period may well be accompanied by adverse economic conditions. At the same time it has complete faith in the industrial and technologic future of the country and intends to follow a broad policy of expansion of Society activities along sound lines even under adverse economic conditions, but of course with careful consideration of each specific activity in its financial as well as its other aspects. It is for this purpose only that the Executive Committee has during recent years of financial prosperity built up the reserve funds, so as to provide a cushion against periods of economic adversity and reduced income and enable the Society to carry on even increased activities in anticipation of the great need for technical information and standards that is certain to develop.

Work of Study Committee:

In its report a year ago, the Executive Committee announced the appointment of a Special Study Committee for the purpose of reviewing the activities of the Society critically and objectively, and of examining and appraising all phases of its work in order to determine whether the Society is organized and functioning in the most effective manner best to serve its members, industry and the nation at large now and in the years to come. The Committee serves under the chairmanship of H. S. Vassar, Past-President of the Society, and consists of eleven members each of whom has had extensive experience in one or more technical phases of the Society's work, as well as important executive and administrative responsibilities in the Society.

The committee has held four two-day meetings and has presented to the Executive Committee three extensive progress reports containing many important recommendations. These cover such matters as: questions of policy as to future development of the Society; extension of A.S.T.M. standardization activities in the field of ultimate consumer goods; the undertaking of work in the field of simulated service tests involving testing of parts and assemblies; a proposed reorganization of the administrative set-up of the Society, including enlargement of the governing body of the Society from an Executive Committee to a Board of Directors, as well as a reorganization of headquarters staff; important recommendations covering the publications of the Society, especially the publication of technical papers and discussions; recommendations concerning the term "tentative standard" and certain standardization procedures; and a number of miscellaneous recommendations of a general nature.

The actions that the Executive Committee has so far taken on these recommendations are indicated in the appropriate sections of this report.

The Study Committee will prepare a complete report of its findings and recommendations, to be ready for presentation at the October meeting of the Executive Committee. This report will constitute one of the most important documents of its kind in the history of the Society and the Executive Committee plans to make it available in appropriate form to the entire membership, possibly by publication in extensive abstract in the ASTM BULLETIN.

The Executive Committee takes this opportunity of thanking the Study Committee for its splendid service to the Society, the full value of which will be appreciated in reading the remainder of this report and when the final report of the Study Committee becomes available.

Extension of A.S.T.M. Standardization Activities in the Field of Ultimate Consumer Goods:

Based initially on recommendations made by the Study Committee and a more extensive examination of the whole subject by a special committee, as announced in the March, 1945, ASTM BULLETIN, the Executive Committee is planning extension of the Society's work in the preparation of standard tests and specifications for ultimate consumer goods. The demand for the development and use of such tests and specifications has been growing rapidly in recent years and has been reflected in the work of the Society in a number of fields, among the more important being textiles, soaps, rubber products, paper, plastics, fuels, paints, and various building materials.

This decision of the Executive Committee was made after a careful appraisal by the above-mentioned special committee of the extent and significance of the consumer movement, activities of various agencies in this field including those of the Government, and the need for consumer goods standards in connection with labeling, grading and certification plans. Anticipating developments in this field within the next decade, it seems clear to the Executive Committee that the Society must prepare to assume appropriate responsibilities for the development of standard tests and specifications for certain types of consumer goods, within proper limitations.

It is intended that the Society's standardization work on ultimate consumer goods shall be based upon sound engineering principles and practices, that it shall proceed deliberately and carefully, based at all times on adequate technical preparation, and that it will deal only with such goods as permit of definitions, test data, and test limitations that can be measured by engineering methods. Work on assemblies of materials will be included only where evaluation of materials or workmanship is concerned, and it is not intended to engage in the formulation of design specifications. Left for later determination are such questions as whether the work should deal principally with manufacturing requirements intended to measure and maintain quality at a predetermined level without emphasis on those factors dependent on human interest and use, or should aim to specify what will give consumer satisfaction at a minimum acceptable level. It is believed that the use factors must be considered; but since definite knowledge and actual test data concerning use characteristics are very limited in most cases of ultimate consumer goods, initial projects will necessarily deal with the development of test methods and specifications for specific uses of such goods concerning which knowledge can readily be obtained.

To implement this program the Executive Committee has appointed a new Administrative Committee on Ultimate Consumer Goods with the following personnel:

Administrative Committee on Ultimate Consumer Goods

H. J. Ball, *Chairman,* Professor of Textile Engineering, Lowell Textile Institute, Lowell, Mass.
A. G. Ashcroft, Director of Research, Alexander Smith and Sons Carpet Co., Yonkers, N. Y.
A. L. Brassell, Vice-President, United States Testing Co., Inc., Hoboken, N. J.
A. W. Carpenter, Manager of Testing Laboratories, The B. F. Goodrich Co., Akron, Ohio.
Jules Labarthe, Jr., Senior Fellow, Mellon Institute of Industrial Research, Pittsburgh, Pa.
G. C. MacDonald, Director, Wards Bureau of Standards, Montgomery Ward and Co., Chicago, Ill.
H. H. Morgan, Vice-President, Robert W. Hunt Co., Chicago, Ill.

This administrative committee has been given responsibility for the planning and administrative direction of this work in the Society. Thus it may initiate projects for reference to committees of the Society as well as receive recommendations from those committees for work in the consumer goods field. It will have authority to recommend the organization of new committees in cases where desired work cannot be handled by existing committees. It must determine the most effective means of providing adequately for representation of the ultimate consumer on A.S.T.M. committees preparing standards for consumer goods and the adaptation of the present committee structure and procedure to the writing of consumer goods standards. The Society's cardinal principle of balance between producers, consumers, and general interests on committees dealing with standards will be maintained, but the application of this principle to different committees may vary in detail in ways to be determined by the administrative committee.

The Executive Committee has referred to the administrative committee a number of important recommendations developed by the special committee relating to such matters as the following: Determination of procedures within the Society for developing ultimate consumer goods standards, possibly with statements for the guidance of committees in the form of a manual; form, arrangement, and content of ultimate consumer goods standards; suggested clauses for inclusion in standards that will clearly define the applicability and possible use limitations of the standards and that will disclaim responsibility of the Society as such for representations such as labeling, certification and advertising based upon the standards; the determination of those ultimate consumer goods that it may be desirable to exclude from an A.S.T.M. program because of such considerations as existing Federal regulations, lack of interest in or demand for standards, or remoteness from present activities of the Society. The administrative committee has also been directed to give careful consideration to the matter of maintaining equivalent standards for the same or similar products used both as industrial and ultimate consumer goods.

The successful development of standards in the ultimate consumer goods field will require more factual knowledge concerning the wants of consumers and more basic data on use values than are now available. Accordingly the Executive Committee, acting upon a recommendation of the special committee, is arranging for the establishment of a project within the Society for the development of techniques for obtaining knowledge of consumer wants and for accumulating data on which to base specifications and methods of test for ultimate consumer goods. This project will be an important aid in the implementation of the entire program and will necessarily utilize social, statistical, psychological, and economic approaches, in addition to those of science and engineering. It is planned to coordinate the Society's work in this particular project with studies that have recently been initiated by the National Research Council and the Social Science Research Council.

The administrative committee held its first meeting on April 11, 1945. The committee has been directed to report periodically to the Executive Committee on the progress of its work and this progress will be suitably recorded in articles from time to time in the BULLETIN.

New Work to be Undertaken in the Field of Simulated Service Testing:

Another important extension of the Society's work based likewise upon a recommendation originating with the Study Committee has been initiated during the year. This may be defined briefly as the study, development and standardization of methods of test of simple or composite materials in actual or simulated service conditions and environment, in so far as performance is dependent on the properties of the material, and including where necessary the testing of processed parts under such conditions. During the past several years many suggestions and recommendations that the Society develop methods of test in this field have been made, these suggestions usually being related to the marked increase in this type of testing in the automotive and aircraft industries. In the field of mechanical testing such things as vibration testing, fatigue, and other forms of life tests of parts and assemblies, as distinguished from such tests of specimens of materials, are involved. As announced in the March, 1945, BULLETIN the Executive Committee appointed last fall a special committee to explore this field of work and report its recommendations, and the Executive Committee's decision is based upon the extensive studies and report of that committee. The following excerpts from that report are helpful to an understanding of the nature of the work it is planned to do and the reasons for undertaking it:

> "It is considered that a proper function of the Society is to recommend methods of

obtaining all the information about the materials that the designing engineer will need to make an informed design. In order to find out whether certain material properties are adequate, or, alternatively, to find out what material properties are needed, it appears necessary in testing to simulate more completely the conditions under which the final product must operate.

"Raw materials tests of themselves are not sufficient to fulfill the needs for modern engineering, where composite materials and processed structures are coming to the fore—a subject which touches not only the scope of activities of A.S.T.M. but that of other engineering societies as well. Accordingly, the present representative committee was invited to discuss the subject in a broad objective way from the point of view of the extent of interest in the testing of parts and assemblies, and whether A.S.T.M. should undertake work in this field.

"It was the consensus of the committee that A.S.T.M. should undertake such work and that there was a proper region of activities where there would be no duplication of effort or conflict with the prerogatives of other societies.

"Any study of a material must have in mind an application. The application involves how the "stuff" is to be shaped or used and the environmental conditions and service experience; so that the "thing" made of it will endure and perform with satisfaction. "Stuff" may be a single raw material or a composite material, such as reinforced concrete, plywood, impregnated textile, plated wire. The effect of the process on the quality of the finished part may be influenced by shape and proportion, as well as the way in which the process is controlled—for example, molded thermosetting parts, die castings, centrifugal castings, drawing, and so on.

"The committee was of the opinon that environmental testing, such as salt spray, humidity, high and low temperature, impact, impact fatigue, vibration, and atmospheric exposure are definitely within the scope of the Society's activities. Many of these are already under investigation. The kind of materials should include composite materials, such as plywood, prefabricated building construction units, and welded, brazed, and soldered parts. In the field of fatigue testing the scope should be extended beyond simplified specimens to show the effect of notches and other surface irregularities. Stress analysis of involved structures, however, is a subject coming under the purview of other technical societies.

"So-called 'Rube Goldberg' tests designed to prove quality of a product seem beyond the scope of A.S.T.M. This would also apply to those tests designed to stimulate desire which have as their object the promotion of sales. On the other hand, the Society should seek to show engineers how fatigue data should be used; that is, formulate methods of good practice in measuring the fatigue properties of a structure.

"The techniques covering the use of laboratory apparatus as applied to materials testing should be extended to cover parts and simple assemblies. Here the thought was expressed that we should stop short of interpretation of results in the form of particular applications, which is the province of design engineering. Portions of structures, such as floor joists, wall panels, plastered surfaces, and jointed pipe, may be tested for performance under simulated service environment. Furthermore, modern process development is tending toward mechanization and this will result in articles of commerce being of composite and prefabricated construction. Specifications and methods of test will be required for such items and these seem within the scope of A.S.T.M. work."

The Executive Committee feels that with respect to present-day requirements for new testing techniques the Society should be imbued with the same pioneering spirit it had forty years ago in facing the testing problems of that day, and that our members and others experimenting with methods—beyond the usual specimen testing—to determine the suitability of materials in many new industrial applications should be able to look to the Society to help them in their work, especially since we have over the years developed methods and procedures whereby such problems can effectively be worked out.

The Executive Committee has appointed a new Administrative Committee on Simulated Service Testing to which it has delegated authority for the development of this new program of activities in all its phases. This authority includes discussion with existing committees of extension of their present programs of work to include various aspects of problems discussed herein, as well as responsibility of recommending to the Executive Committee the formation of such new committees as may appear desirable. The personnel of the administrative committee is as follows:

Administrative Committee on Simulated Service Testing

L. L. Wyman, *Chairman*, Research Metallurgist, Research Laboratory, General Electric Co., Schenectady, N. Y.
H. O. Boyvey, Chief of Development Labs., Engineering and Development Department, Consolidated Vultee Aircraft Corp., Vultee Field, Calif.
J. M. Frankland, Supervisor of Structures Tests, Chance Vought Division of United Aircraft Corporation, Stratford, Conn.
D. E. Parsons, Chief, Masonry Construction Section, National Bureau of Standards, Washington, D. C.
R. E. Peterson, Manager, Mechanics Division, Westinghouse Research Labs., Westinghouse Electric Corporation, East Pittsburgh, Pa.
S. B. Ritchie, Colonel, Ordnance Department, United States Army, Washington, D. C.
R. L. Templin, Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.
E. W. Upham, Chief Metallurgist, Chrysler Corporation, Detroit, Mich.

The administrative committee held its first meeting on April 18, 1945. The committee has been directed to report periodically to the Executive Committee in the progress of its work and this progress will be suitably recorded in articles from time to time in the BULLETIN.

Administrative and Staff Organization:

One of the most important subjects under consideration by the Study Committee has been that of the administrative organization of the Society, including the constitution of the governing body of the Society (that is, the Executive Committee), the organization and procedures of standing, administrative, special and other committees, and the organization of the headquarters staff. These are important because it is essential that the administration of Society affairs shall be on the soundest and most efficient basis possible and that it be suited to the future development of the Society in so far as this can be foreseen. Over the past fifteen years the Society has grown greatly both in numbers and extent of technical activities, during which time there have been no important changes in its administrative set-up, and the Study Committee came to the conclusion that certain changes in administration and procedure are now advisable.

The committee accordingly submitted a number of recommendations, carefully documented and substantiated, which were unanimously adopted by and are herewith presented as actions and recommendations of the Executive Committee. The explanations of and reasons for the changes recommended are taken from one of the progress reports of the Study Committee.

A Board of Directors Proposed.—The most significant recommendation has to do with the enlargement of the governing body of the Society and the change in name of that body from "Executive Committee" to "Board of Directors." With the increase in Society membership, the increase in number of industries represented in the Society's activities, and the greater emphasis on the work of our geographically established district committees, it has become highly desirable to enlarge the governing body of the Society so as to afford better opportunity for more frequent representation thereon of various industrial and technical groups and of the geographic districts. It is proposed to accomplish this by providing for fifteen Directors serving for terms of three years, in place of ten Members of Executive Committee serving for terms of two years, with the Directors so classified that the terms of office of five Directors shall expire each year. The three-year term is recommended to give greater continuity to membership on the governing body; under the present two-year term the member must retire from service at a time when he has become thoroughly familiar with Society problems, and it is believed that a third year of service would contribute to the effectiveness of the direction of Society affairs. Such an enlarged body is more appropriately designated as a Board of Directors than as an Executive Committee; moreover, it is desired to use the term Executive Committee for another purpose, as described below. It is proposed that the Board of Directors shall comprise the President, the two Vice-Presidents, the fifteen Directors and the last three Past-Presidents, but not the Secretary-Treasurer, since that office is appointive by the governing body and not elective by the Society.

It is further proposed that the Board of Directors shall be empowered to appoint from its membership a small committee (not over six in number), to be designated the Executive Committee, which shall exercise at times when the Board of Directors is not in session such part of the authority of the Board in the administration of the Society's affairs as the Board may from time to time delegate to it. It is contemplated that the Executive Committee will relieve the Board of Directors of detailed consideration of many routine matters that at present of necessity come before the entire governing body, so that the Board can give its major attention to matters of Society policy and advancement.

It is further recommended that the Board of Directors shall hold three regular meetings during the year, with the thought that the smaller Executive Committee can meet more frequently as the business of the Society may require.

The Executive Committee also recommends that the title of "Secretary-Treasurer" be changed to that of "Executive Secretary," believing that the latter is a more suitable one and better describes the duties and responsibilities of the office of Secretary-Treasurer as now defined. It is at the same time proposed that the Board of Directors shall be empowered to appoint an Assistant Executive Secretary, a Treasurer and an Assistant Secretary and such other assistants to the Executive Secretary as the Board may consider desirable.

In order to effect these changes in the administration of the Society, appropriate amendments of the By-laws are required. Such amendments, together with certain other amendments of the By-laws, were formally proposed to the membership by Letter Circular to Members No. 264 dated May 25, 1945, to which reference is made in a later section of this report. Particular attention is called to the method recommended in a new Article XI to provide for the transition period prior to the formal institution of the Board of Directors.

Committees of the Board.—It is believed that the present six committees of the Executive Committee have proved adequate for the purpose of detailed consideration of various lines of work. However, in view of the decision recorded elsewhere in this report that consideration of district activities shall be assigned to a new administrative committee, it is planned to change the present "Committee on District Committee and Promotional Activities" to a "Committee on Developmental Activities." The new Board of Directors would then have serving under it, in addition to the Executive Committee as described above, the following six committees: Finance, Membership, Meetings and Program, Developmental Activities, Technical Committee Activities, and Inter-Society Relations.

It is further intended that the Board may appoint special committees from its membership as needed for consideration of problems of unusual importance not comprised in the scope of its regular committees.

Classification of Society Committees.—The following classification of committees of the Society has been adopted:

(1) *Technical Committees,* to comprise committees charged with the carrying on of research and standardization of materials (now designated as "standing committees"). Included in this category are all committees now in the A, B, C, and D groups and Committees E-1, E-2, E-3, E-4, E-7, and E-8; also research committees, sectional committees under A.S.A. procedure, and joint technical committees with other bodies. The members of technical committees will be appointed or elected as at present and no change is recommended in the methods of functioning or procedure.

(2) *Administrative Committees,* to be appointed by and report to the Board of Directors and to which the Board assigns certain administrative duties and responsibilities, including also the function of serving in an advisory capacity to the Board. It is intended that the headquarters staff shall continue to provide the secretariat for administrative committees.

Present committees in this category are: E-5 on Standing Committees, E-6 on Papers and Publications, E-9 on Research, and E-10 on Standards.[1] It is proposed hereafter to omit the letter designation from these committees, using simply the term, for example, Administrative Committee on Standards. As noted elsewhere in this report the Executive Committee has already added three new committees to this category, namely, Administrative Committees on District Activities, on Ultimate Consumer Goods and on Simulated Service Testing.

(3) *Special Committees,* to be appointed by and report to the Board of Directors, to work upon special assignments and be discharged when such assignments are completed. Examples of special committees at present are the Committees on Edgar Marburg Lecture, Dudley Medal Award, and Headquarters.

(4) *District Committees,* which are presently appointed by the Executive Committee and function under the terms of a Charter for District Committees. No changes in the present arrangement are proposed, although the newly appointed Administrative Committee on District Activities is engaged in reviewing all phases of district activities, including the manner of appointment and the functions of the district committees.

Organization of Headquarters Staff.—Much thought has been given to the organization of the headquarters staff along lines better suited to the technical and business activities of the Society as they have grown and developed, especially in the past five to ten years. A thorough study was made of present and potential duties of the staff, which led to the conclusion that the staff should be organized under five departments with approximate responsibilities as follows:

(1) *Technical Activities Department* headed by a Technical Secretary and responsible for all administrative contacts with the technical committees of the Society, including research committees, and with joint and sectional committees; for technical cooperation with Governmental agencies; and for technical and committee sessions of national and district meetings. This will include administrative responsibility for research, development of tests and specifications, reports, special articles, etc.; expansion of technical activities; committee membership and records; committee meetings, minutes; technical inquiries and correspondence.

(2) *Editorial Department* headed by an Editor and responsible for the editing and printing of all publications; also responsible for technical library.

(3) *Field and Secretarial Department* headed by an Assistant Secretary and responsible for the following activities: District activities, including meetings and

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[1] The By-laws of the Society confer special powers on Committee E-10 in respect to passing upon tentative standards. No change in this arrangement is proposed.

programs, personnel records, reports, etc.; exhibits and certain phases of national meetings; developmental activities including membership, publication sales and general publicity; advertising; and miscellaneous secretarial duties.

(4) *Finance Department* headed by a Treasurer and responsible for membership records, including geographical and industrial classifications and correspondence; receipt and disbursement of all monies of the Society; accounting, cost and other financial records, including those of the Employees Retirement Plan; and custody of securities.

(5) *Office Management Department* headed by an Office Manager and responsible for the following activities: Distribution and sales of publications, including shipping and stock records; mail, addressograph and duplicating work; general files; office supplies; and the general problems of office management, including headquarters maintenance, telephone switchboard, etc.

One of the most important changes of policy involved in this method of organizing the staff is the decision to expand and improve the staff contacts with the technical committees of the Society. The work of these committees is steadily increasing and with the growing ramifications and inter-relationships of the materials field there is increasing need for closer coordination of their activities. This will be greatly facilitated by having staff men assigned to selected groups of committees to attend their meetings and assist the committee and subcommittee officers in various ways—to be in effect a liaison between the technical committees and the administrative groups of the Society in matters of policy, procedure, expansion of activities, development of standards and reports, and the like. This work will be one of the important assignments of the Technical Activities Department and it is the intention of the Executive Committee to add qualified persons to the headquarters staff for these purposes. The appointment last fall of Carter S. Cole as Staff Engineer was the first of such appointments.

When the organization of the headquarters staff along the lines above indicated has been completed, the Executive Committee is confident that the staff will be better fitted to perform the enlarged activities and responsibilities that lie ahead of it. It is realized that all it is desired to do cannot immediately be accomplished, but the major elements of the plan will be effectuated as soon as possible.

New Society Headquarters:

As recently announced to the membership in Letter Circular No. 265 under date of June 22, 1945, the Executive Committee has taken one of the most important steps in the Society's history, namely, the purchase of a property to become a permanent headquarters from which the Society can more effectively serve its members in the future. The story is told so fully in the Letter Circular that this report need include only the principal features of the project.

As most of our members know, the Society's offices have throughout its existence been maintained in rented space—first, at the University of Pennsylvania; then, beginning in 1919 at the Engineers' Club of Philadelphia; and finally in the Atlantic Building at 260 South Broad St., Philadelphia, where space first leased in 1933 has been twice expanded to provide the present quarters. While these have well met the Society's requirements they are now badly crowded and further expansion in the present location is impossible; in fact, the Executive Committee learned toward the close of last year that it would not be possible to renew the present lease expiring December 31, 1945.

The extension of research and standardization into new fields has greatly increased the Society's services, especially in the form of new publications, all of which has required substantially increased technical and clerical personnel and publication storage and shipping facilities. The staff has more than doubled in the past decade and with the intensive technical work already in sight for the post-war era and the consequent staff expansion the headquarters requirements will continue to grow.

Anticipating these developments, and realizing that the acquiring of larger quarters under present rental conditions would entail substantially increased costs of operation, the Executive Committee over a year ago began to consider the desirability of discontinuing leasing entirely and of buying a suitable building to provide a permanent home for the Society. A Special Headquarters Committee was appointed to study the situation and if possible to locate a property in or near the central business district of Philadelphia that would meet our requirements. This Committee consists of Messrs. Judson F. Vogdes, Jr., *Chairman*, E. J. Albert, G. H. Clamer, P. H. Dike, and Alexander Foster, Jr. After thorough canvassing of available properties, this committee recommended the purchase of the building at 1916–18 Race St., Philadelphia; the Executive Committee concurred in the recommendation and has executed an agreement of sale for which settlement will be made on August 1.

About the Property.—The property faces the Benjamin Franklin Parkway at Logan Square about one-half mile northwest of Philadelphia's City Hall. Facing the Square on the west is the Franklin Institute and on the north the Philadelphia Public Library—both valuable to the Society in its work. Immediately to the east is the Academy of Natural Sciences. The Parkway is one of Philadelphia's finest avenues, with building and zoning restrictions on adjoining areas such as to insure for all time the beauty and dignity of this thoroughfare.

The building occupies about eighty per cent of the area of a lot 40 by 130 ft. It consists of a basement, three stories and a penthouse, of substantial masonry construction, with limestone facing on the front and side. An 18-ft. driveway on the property of the Academy of Natural Sciences separates it from that building on the east, giving excellent light on three sides. A street in the rear provides convenient access for deliveries and for shipment of publications. Central steam heat is an attractive feature.

There are about 11,000 sq. ft. of available space which is over twice that presently occupied, and there is room for expansion in later years if necessary by building over the present one-story structure in the rear.

Considerable interior alteration will be required, for it is the desire of the Executive Committee to remodel the building in the most effective way to meet the Society's requirements for its general offices, its library, facilities for the storage and distribution of its publications, and as headquarters for officers, directors and members of the Society and for conferences of its administrative and other committees. The services of an architect have been retained, and plans and specifications for the alterations and improvements are being developed. Particular attention will be given to the adequacy of facilities for the members and committees of the Society.

It is realized that the complete plan for remodeling may not be immediately possible of accomplishment because of present war-time restrictions. It is proposed, however, to work to the complete plan as closely as present conditions will permit and, where necessary, to defer installation of equipment and materials till they become available.

The property will afford, the Executive Committee believes, an ideal solution to the headquarters problem—it will provide space and facilities for staff and members' use adequate for many years, free us from the uncertainties inherent in the use of leased space, and give to the members a distinctive headquarters more nearly commensurate with the high standing and prestige of the Society.

The decision to maintain the Society headquarters in Philadelphia was made by the Executive Committee after carefully weighing the pros and cons of other locations, such as New York, Washington, and Chicago, each of which has at one time or another been mentioned. In particular, New York has been suggested by various members because of the location there of the Engineering Societies Building, but such a move has not been favored for a number of reasons, not the least of which is the greatly increased cost of operation there. Since Philadelphia has proved over the years to be well suited to the conduct of the Society's work and is known the world over as the home of A.S.T.M., the Executive Committee is convinced that the decision to remain in Philadelphia is wise and will meet with the approbation of the members.

Financial Aspects.—The property is being obtained at a favorable price, so that with the excellent location and the expectation of enhancement of values adjacent to the Parkway, the purchase is a sound one. The ultimate cost is estimated at $125,000, including the extensive alterations required, improvements, and new furnishings. The Executive Committee believes that to use the Society's reserve funds in the financing of this project would jeopardize the continued technical service of A.S.T.M. to its members and to industry, since these reserves have been built up in recent years solely to meet the demands of expanded technical activities and to provide against future periods of economic adversity and reduced income. To borrow the necessary funds would still require in the future the use of current income or reserves for interest and amortization of indebtedness, at the expense of the development of our technical services.

If the building can be owned by the Society clear of indebtedness, it is conservatively estimated that the new headquarters can be operated at an annual expense actually no more than the present rental and less than half that of renting equivalent space in a suitable location. Thus the overhead expense of maintaining headquarters would be kept to a minimum and the Society's income used to the maximum possible extent for the advancement of its technical work.

$125,000 Building Fund.—The Executive Committee accordingly decided to appeal to the membership of the Society for contributions to an A.S.T.M. Building Fund of $125,000, which if realized will make it possible for the Society to own its headquarters completely clear of indebtedness. Letters of invitation to contribute to this Fund have been addressed to a limited number of the active company members of the Society, and with the above mentioned Letter Circular there was extended to all members, individuals and companies alike, an invitation to subscribe to the Fund. The response to these invitations has been most gratifying, evincing a keen interest in seeing the Society located in a permanent home and a desire to lend substantial financial support to make such a home possible. As this report is written subscriptions have reached a total of nearly $70,000.

It is to be understood that the Building Fund will be used only for capital expenditures—that is, purchase of property, alterations and improvements, and furnishings—not for operating expenses, which will be met from current income.

The Executive Committee has taken this important step in the confident belief that the membership will agree that it is in the best future interests of the Society and that we are most fortunate in having located so suitable a property in the emergency that faced the Society. With the successful establishment of the Building Fund through the generous support of the members, 1946 will see us established in the new Society-owned Headquarters in which the entire membership can take great pride.

Proposed Amendment of By-Laws:

In accordance with the provisions of the By - laws governing amendments thereof, the Executive Committee submitted to the membership of the Society under date of May 25, 1945, through Letter Circular to Members No. 264, proposals that the By-laws of the Society be amended as set forth in detail in the Letter Circular. For convenience and to facilitate comparison, the present By-laws and the proposed amended By-laws were published in parallel columns.

The proposed amendments were approved at the meeting of the Executive Committee on April 10, 1945, for submission to the Society at the Annual Meeting on Wednesday, June 27, and in accordance with that action they are herewith presented for consideration of the meeting with the recommendation of the Executive Committee that they be referred to a letter ballot vote of the Society for adoption.[2]

The proposed amendments are intended to accomplish the following principal purposes:

(1) *More Suitable Classification of Members.* This is accomplished in the proposed amendments of Article I, by subdividing the present class of "Member" into two classes, "Individual Member" and "Company Member," and defining more precisely what is meant by Individual Member, Company Member and Sustaining Member. The new classification is in line with usage that has come about in the years since the dues of "Company Members" were raised to $30 and the class of Sustaining Member at $100 dues was established. Furthermore, the new classification facilitates the statement of the amounts of the annual dues for the several classes of membership in Article VIII. *It is to be noted that no change in the annual dues of any member is involved in the proposed amendments of Articles I and VIII.*

(2) *Broader Qualifications for Honorary Membership.* The Executive Committee believes that persons who have rendered "especially meritorious service to the Society" should be eligible for election to honorary membership; also, in view of the growth in society membership since the class of honorary member was first established in 1912, that the limit upon the number of such members should be increased from ten to twenty. These purposes are accomplished in the proposed amendment of Article I, Sec. 5 (new Sec. 7).

(3) *Elimination of the Provision for Membership in Perpetuity.* This purpose is accomplished by striking out of Article VIII, Sec. 3, the following sentence: "The cost of membership in perpetuity to companies, firms, corporations, industrial associations and commercial testing laboratories shall be $600; to other organizations, $300." The Executive Committee believes that retention of this provision is no longer advisable in view of the establishment in recent years of the class of sustaining membership at annual dues of $100, which it is desired to promote as an effective means for companies to give increased financial support to the Society's activities. Furthermore the variability of earning power of investments is such that the amounts specified for acquisition of membership in perpetuity are frequently inadequate for the purpose. Thus the amounts at present specified were fixed so that at 5% they would provide annual income of $30 and $15, respectively, but today only about half this income is returned from memberships in perpetuity acquired under the present By-laws.

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[2] The amended By-laws were approved by letter ballot vote of the Society canvassed on September 15, 1945. The By-laws as revised are published in the 1945 A.S.T.M. Year Book, p. 433.

It is to be understood, however, that the adoption of the proposed amendment will not affect the status of the nine members of the Society that now hold membership in perpetuity.

The Executive Committee believes it is desirable to retain the provision, customary in the technical and professional societies, whereby a *person* may acquire a life membership.

(4) *Substitution of a Board of Directors for an Executive Committee as the Governing Body of the Society.* This is the most important of the amendments recommended by the Executive Committee and is discussed fully in another section of this report. Briefly, the proposed amendments are designed to provide for fifteen Directors serving for terms of three years, in place of ten Members of Executive Committee serving for terms of two years, with the Directors so classified that the terms of office of five Directors shall expire each year. It is then proposed to designate the new governing body as the Board of Directors, comprising the President, two Vice-Presidents, fifteen Directors and the last three Past-Presidents continuing to be members. The Board of Directors would be empowered to appoint from its members a small Executive Committee (not over six in number) to which the Board of Directors may delegate such of its authority as it may from time to time determine. It is further proposed that the Board of Directors shall hold three regular meetings a year, with the thought that the Executive Committee, being smaller, can meet more frequently as the business of the Society may require.

These changes in administrative set-up are accomplished by the amendments proposed in Articles II and IV.

A new Article XI is proposed as the most effective means of providing for the transition period between adoption of the amendments and the time that the new Board of Directors starts to function. Under the provisions of this Article, if adopted, the ten Members of Executive Committee in office after the close of the 1945 annual meeting will have one year added to their respective terms and will take office as Directors at the close of the 1946 annual meeting. Then at that annual meeting the Society will elect by prescribed procedure a President for a term of one year, a Vice-President for a term of two years, and five Directors for a term of three years.

(5) *Change in Title of "Secretary-Treasurer" to "Executive Secretary."* The Executive Committee believes that the title "Executive Secretary" is a more suitable one and that it better describes the duties and responsibilities of the office of Secretary-Treasurer as now defined. Provision for this change is made in the amendment of Article II, Sec. 1; and by the amendment of Article II, Sec. 5 the Board of Directors would be empowered to appoint an Assistant Executive Secretary, a Treasurer, an Assistant Secretary, and such other assistants to the Executive Secretary as it may desire.

(6) *Substitution of the Collective Noun "Tentatives" for "Tentative Standards."* This is an editorial change in keeping with an earlier decision of the Executive Committee and is discussed elsewhere in this report. It affects only Article VII, which prescribes the procedure governing the adoption of standards. No changes whatever in this procedure are being proposed.

The remaining proposed changes in the By-laws are purely editorial in nature, involving mainly the substitution of the words "Board of Directors" for "Executive Committee" and "Executive Secretary" for "Secretary-Treasurer" wherever they appear in the By-laws. No changes other than editorial are proposed in Nomination of Officers, Article III; Meetings, Article V; Administrative and Other Committees, Article VI; Resignations, Article IX; and Amendments, Article X.

Members not planning to attend the annual meeting have been invited to send their comments on these proposed amendments to the Executive Committee, in order that their views may be taken into consideration.

Proposed Amendment of Charter:

As explained in the above-mentioned Letter Circular to Members No. 264, dated May 25, 1945, the proposed substitution of a Board of Directors for an Executive Committee as the governing body of the Society will necessitate an amendment of the Charter of the Society,[3] inasmuch as that document in

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[3] The Charter is published in the 1944 A.S.T.M. Year Book, pp. 366–67.

Sections 6 and 8 thereof specifically names an Executive Committee as the managing body of the corporation. The amendment of the Charter can be made only through court approval under the provisions of the laws of the Commonwealth of Pennsylvania. The law provides that before application is made to the court for amendment, a resolution authorizing the proposed amendments shall be adopted by the affirmative vote of at least a majority of the members entitled to vote thereon at a regular or special meeting duly convened after at least ten days written notice to all members for this purpose.

Accordingly, in order that the amendments of the By-laws of the Society relating to the establishment of a Board of Directors as the managing body of the corporation may become legally effective, the Executive Committee, having unanimously approved the proposed amendments of the Charter at its meeting on April 10, 1945, notified the members of the Society in the Letter Circular that it will submit the following resolution to the Annual Meeting with recommendation for favorable action:

RESOLUTION

WHEREAS, the annual meeting of the Society has voted to refer certain amendments of the By-laws of the Society to a letter ballot of the entire membership in accordance with the terms of Article X of the By-laws; and

WHEREAS, these amendments include, *inter alia*, a proposal to substitute a Board of Directors for an Executive Committee as the body in which the general management of the Society will be vested; and

WHEREAS, the Charter of the Society specifically names an Executive Committee in which such management shall be vested; and

WHEREAS, amendment of Sections 6 and 8 of the Charter is necessary before the related amendments of the By-laws may become effective; and

WHEREAS, such purpose may be effected by changing Sections 6 and 8 of the Charter to read as follows:

"Section 6. The management of the said corporation shall be vested in a Board of Directors, consisting of the President, two Vice-Presidents, fifteen Directors, and the last three Past-Presidents continuing to be members, and such other officers as the corporation may from time to time appoint."

"Section 8. The By-laws of this corporation shall be admitted and taken to be its laws subordinate to the statute aforesaid; this charter; Constitution and Laws of the Commonwealth of Pennsylvania, and the Constitution of the United States; they shall be altered and amended as provided for by the By-laws themselves; and shall prescribe the powers and functions of the Board of Directors herein mentioned and those to be hereafter elected, the times and places of meetings of the Board and this corporation; the number of members who shall constitute a quorum at the meetings of the corporation, and the Board; the qualifications and manner of electing members; the manner of electing officers; and the powers and duties of such officers; and all other concerns and internal arrangements of the said corporation."

Now, Therefore, Be It

RESOLVED, that the American Society for Testing Materials in annual meeting assembled, after due and legal notice in accordance with the laws of the Commonwealth of Pennsylvania, approves the above proposed amendments of Sections 6 and 8 of the Charter of the Society and authorizes the President to present to the court appropriate Articles of Amendment to the Charter and to take such further action as may be required by the laws of the Commonwealth of Pennsylvania to effectuate the aforesaid amendments to the Charter.

Consideration of and action upon the proposed amendments of the Charter will accordingly take place at the Annual Meeting of the Society on Wednesday, June 27. In order that members of the Society unable to attend the annual meeting shall have opportunity to express a vote on the proposed amendment to the Charter, a ballot was enclosed with Letter Circular No. 264 which the members were invited to mark and return—such vote to have the same effect as if cast in person at the annual meeting. Thus a representative expression of the wishes of the membership will be obtained.

Committee Activities:

In this fourth year of the war many committees of the Society have been unusually active, being engaged upon the development of tests and specifications for materials of direct importance to the war effort. Many of the committees, however, especially the larger ones, have for the first time been adversely affected by the restrictions on wartime travel and meetings imposed by the Office of Defense Transportation. Some of the committees have been unable to hold their usual spring meetings and in such cases wherever possible subcommittee reports are being acted upon by letter vote. Other committees have brought together the work of their subcommittees in the form of progress reports, but without recommendations affecting standards, which will be considered as soon as it is possible for meetings to be held.

Despite these difficulties many of the committees are reporting to the Society at this annual meeting. All recommendations affecting adoption as standard will be considered at the meeting for reference to the usual letter ballot vote; all recommendations affecting new or revised tentative specifications, methods, etc., will for this year be handled entirely by the alternate procedure through the Committee on Standards provided for in the By-laws. Articles in recent issues of the ASTM BULLETIN have kept the members currently informed of the more important committee activities and a review article planned for the August issue will summarize actions of the Annual Meeting and of the Committee on Standards.

In the report a year ago the Executive Committee announced the decision to form a new Committee D-14 on Adhesives. This committee was organized on June 20, 1944, with the following scope:

> "The formulation of specifications, methods of test and definitions of terms pertaining to adhesives, including animal, vegetable, mineral and the synthetic types."

Six subcommittees have been formed to which various types of tests and specifications have been assigned for study. Some progress has been made and the work of the committee will be further advanced through a series of meetings to be held this month at which informal papers summarizing present knowledge of various properties of and tests for adhesives will be presented and discussed.

As announced a year ago, the scope of Committee D-7 on Timber (now Committee D-7 on Wood) was expanded to include the fields of plywood and wood laminates. During the year the following statement of scope was adopted for the committee:

> "Nomenclature, quality classifications, specifications, methods of test, methods of and materials for modifying properties, effect of various factors on the properties, questions of utility, and related subjects pertaining to wood, modified wood, veneer, plywood, and wood- and wood-base laminates."

The committee has brought into its membership several new members especially qualified on the subject of plywood and is presently engaged in a substantial expansion of its personnel.

During the year the activities of Committee D-10 on Shipping Containers have been revived. This committee had been inactive for some time but the importance of packaging problems in the war effort and the urgent need for standard methods of test for various types of containers led to the assignment of specific problems to the committee at the request of the War Production Board that the Society develop a series of test methods for shipping containers. A number of new members have been added to the committee so that various groups of producers and users of the several types of containers will be effectively represented. An organization meeting of the enlarged committee was held in New York City on March 22, 1945, at which considerable progress was made in the development of a number of test methods. Some of these will be recommended to the Society in the near future for acceptance as tentative and others are being given further study by the committee. The scope of the committee was revised as follows:

> "The formulation of performance specifications, methods of test, and definitions of terms pertaining to shipping containers. The term 'shipping container' as used herein shall mean the complete container with any or all interior packing."

The Executive Committee is at present considering the relationships of the scope of this committee and that of Committee D-6 on Paper and Paper Products, as pertaining to fiberboard containers.

Following are other actions during the year on titles and revised scopes of standing committees:

Committee B-5 on Copper and Copper Alloys, Cast and Wrought:

> "The scope of the committee shall be copper ingot for remelting, and commercial cast copper and wrought copper products directly intended for industrial use, including all alloys founded upon copper as a base material used in cast or wrought form. Not included are copper cathodes; or copper cakes, slabs, billets, wire bars, etc., intended for rolling to finished shapes; copper alloy die castings; and copper and copper alloy wire specified for use as electrical conductors."

Committee D-11 on Rubber and Rubber-Like Materials (formerly Committee D-11 on Rubber Products):

> "Formulation of specifications, methods of test, and definitions of terms pertaining to rubber and rubber-like materials and products therefrom, including research concerning the properties of such materials and products."

Committee D-17 on Naval Stores:

> "The formulation of specifications, methods of test, and definitions relating to the products generally included in the term 'naval stores,' which includes turpentines, rosins, pine oleoresins, pine oils, resin oils, tall oils, wood tars, wood pitches, and other closely related natural resinous materials."

Committee D-18 on Soils for Engineering Purposes:

> "The formulation of specifications and methods for the sampling and testing of soils for civil engineering purposes, the selection of acceptable nomenclature and definitions, and the promotion of research activity in the general field of properties and behavior of soils for civil engineering purposes."

The Executive Committee has under consideration a recommendation of Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors that its title be changed to read: "Wires for Electrical Conductors," and its scope re-defined as follows: "Specifications and methods of test for uninsulated wire for electrical conductors, solid, stranded, and braided." The Coordinating Committee on Non-Ferrous Metals and Alloys has been requested to consider this recommendation and to secure the advice of interested ferrous metals committees.

The Executive Committee presently has under consideration questions of possible overlapping in jurisdiction and scope affecting Committees D-11 and D-14 as to adhesives, D-1 and D-17 as to turpentine, and D-1 and D-16 as to certain aromatic hydrocarbons.

In line with recommendations from the committee itself, the Coordinating Committee on Non-Ferrous Metals and Alloys has been re-constituted to consist of the chairman and secretary of each B committee. It was further agreed that the Secretary-Treasurer or his designated representative would serve *ex-officio* as chairman of the Coordinating Committee and Carter S. Cole, Staff Engineer, has been so designated.

The Executive Committee has called attention of the various committees now specifying requirements for standard conditions of temperature and humidity, to the lack of uniformity in this field and the desirability of standardizing on a single set of humidity and temperature conditions. This was done through the medium of Subcommittee X, of Committee E-1, on Conditioning and Weathering upon which are represented all committees of the Society having an interest in this subject. Certain modifications in the A.S.T.M. Tentative Definitions with Procedures Relating to Conditioning and Weathering (E 41 – 42 T) under consideration in Committee E-1 on Methods of Testing will serve to call attention to the situation as it exists today and to the desirability of trying to work to a common standard.

Much thought has been given to the part that the Society might helpfully take in the development of Quality Control of Materials—an activity stemming from work on statistical analysis of test data and the application of the science of statistical analysis to the control of quality. This has been greatly stimulated by the need for improved methods of control of the quality of war materials and products, and extensive courses conducted by the Army in various war production centers have aroused a great deal of interest in the subject. The Society has made several important contributions in this general field through the work on presentation and interpretation of data begun some years ago under the auspices of Committee E-1 on Methods of Testing and reflected in the Manual on Presentation of Data. It seems clear that this work needs to be brought up to date and such further information developed as will serve members of the Society in the field of quality control. In addition there is another important field that should be covered, namely, the application of statistical controls to the planning of research and experiment. The Executive Committee has concluded that the entire subject is of such importance as to justify the formation of a separate standing committee on Quality Control of Materials of sufficiently broad scope to bring various phases of the problem under unified direction. The Secretary-Treasurer has been authorized to proceed with the organization of such a committee and to take carefully into consideration the coordination of this work with the activities of other bodies, notably committees of the National Research Council and the Social Science Research Council.

In view of the fact that the patent on the Union Colorimeter held by the Sinclair Oil Corporation has expired, the agreement between the Society and the Sinclair Oil Corporation respecting the references to the patent in A.S.T.M. Method D 155 – 39 T, as well as an exclusive license given by the Corporation to C. J. Tagliabue Manufacturing Co., have been terminated. Accordingly Committee D-2 on Petroleum Products and Lubricants in charge of the aforesaid method has approved the deletion of the following sentence from Section 2 (*a*) of the method:

> "The A.S.T.M. Union Colorimeter shall bear a metal nameplate marked with the following description and a serial number:
>
> A.S.T.M. Union Colorimeter
> Licensed under U. S. Patent No. 1,495,763."

Details of editing of the method are being taken up with Committee D-2.

In consideration of the fact that on many of our standing committees some members stand in the relation of consumer to certain products and in that of producer to other products within the province of the committee, it has been arranged on the recommendation of the Study Committee that the standard letter ballot used by standing committees be revised by adding a fourth column wherein with respect to each item the voter may state his classification as consumer, general interest, or producer. This will materially assist the committee officers in canvassing and reporting results of ballots. (For copy of revised ballot see 1944 Year Book, page 382.)

District Committees and Meetings:

A number of notable technical meetings were sponsored by the various District Committees, condensed information on these appearing in the accompanying table. All but one of the districts held such sessions.

Undoubtedly the Symposium on Magnetic Particle Testing, in Philadelphia, was the most extensive meeting, comprising two sessions with eight technical papers, but sessions in Detroit with three speakers on Life Testing of Materials, the two Philadelphia meetings on Hardenability of Steel and Experimental Stress Analysis (two sessions) and the meeting in New York on Processing Materials from Petroleum drew large audiences of members and visitors.

For most of these meetings invitations were extended to the members of local societies and chapters of national organizations because the technical subjects covered usually were of interest to rather broad cross-sections of technical men. This policy has the advantage of promoting a knowledge not only of the properties and tests of materials, but also the effective A.S.T.M. work in materials.

The Pittsburgh District Committee had planned an extensive Symposium on Corrosion Prevention to feature the 1945 Spring Meeting of the Society during A.S.T.M. Committee Week, but as noted later this Spring Meeting was cancelled.

The District Committees in Cleveland, Detroit, and Chicago continued their affiliation with the councils or societies of local sections and chapters in the engineering field, and in New York and Chicago the committees cooperated in War Production Conferences sponsoring sessions on topics of concern to the field of materials. The Pittsburgh District has joined with other societies in that area in sponsoring the publication of the "Pittsburgh Technical Calendar" distributed monthly listing the meetings of all participating societies, and it is expected the New York District Committee will participate as an active member of the Northern New Jersey technical societies group which likewise is distributing regularly a calendar of meetings of various societies. News articles on all of the district meetings have appeared in the ASTM BULLETIN, and abstracts of many of the papers have been included; some of the papers have been published in full. The Symposium on Magnetic Particle Testing will be issued in book form later in the year.

President Bates has visited many of the districts (as senior Vice-President he addressed meetings of the Southern and Northern California Districts in May 1944) and has been a speaker at these meetings, covering either the subject of portland cement and concrete, or activities at the National Bureau of Standards of interest to materials engineers. Some member of the Headquarters Staff has usually attended the meetings.

The Executive Committee is appreciative of the intensive efforts which the officers of the District Committees and the district members have devoted to meetings and other work in furthering the purposes of the Society.

Administrative Committee on District Activities:

In order better to coordinate district activities and in recognition of the place of increasing importance which districts are assuming in Society activities, the Executive Committee (acting upon a recommendation of the Study Committee) has appointed an Administrative Committee which will have responsible charge for the Executive Committee of all district work. Each of the members of the committee has been very active in Society work and has participated in the work of his respective district. The committee was organized at a meeting in Detroit on May 15, 1945, and a number of recommendations are being developed. Revisions in the charter for districts are being studied and a manual for the guidance of districts, essentially a compendium of good practice, has been drafted. There has been referred to the committee a number of recommendations pertaining to district activities considered by the Executive Committee during the year, including a series of recommendations submitted to the Executive Committee a year ago in a report by Past-President Harvey on his retirement from the presidency. The personnel of the committee follows:

Administrative Committee on District Activities

C. H. Fellows, *Chairman*, Head, Chemical Division, Research Dept., The Detroit Edison Co., Detroit, Mich.

Theodore P. Dresser, Jr., Chief Engineer, Abbot A. Hanks, Inc., San Francisco, Calif.

W. H. Lutz, Technical Director, Pratt & Lambert, Inc., Buffalo, N. Y.

J. deN. Macomb, Assistant to Vice-President, Inland Steel Co., Chicago, Ill.

R. W. Orr, RCA Victor Division, Radio Corporation of America, Camden, N. J.

F. G. Steinebach, *The Foundry*, Vice-President and Secretary, Penton Publishing Co., Cleveland, Ohio.

National Meetings:

In the accompanying table are listed all meetings of a national or district nature held during the past year, including the 1944 Annual Meeting. Notes on some of the outstanding meetings have been given in the preceding section of this report. The annual meeting in New York in June and a joint meeting with the American Institute of Mining and Metallurgical Engineers in November were outstanding events and some notes on these are desirable for this record.

Annual Meeting in New York, N. Y., June 26–30, 1944.—The Forty-seventh Annual Meeting of the Society, held in New York, N. Y. because of the large concentration of members and committee members in the metropolitan and neighboring areas, resulted in the largest attendance by far at any meeting, with total registration of 2063, including 1185 members, 368 committee members, and 510 guests. Actually the attendance was greater than the recorded figures. While the meeting was planned in full cognizance of the wartime conditions, with technical sessions and all functions confined strictly to technical work, it was necessary to have sixteen sessions in order to provide sufficient time for the presentation of the large number of technical papers and reports; and there were some 300 technical committee meetings, this large number due in part to the fact that many of the committees had deferred holding meetings until the Annual Meeting, but also in considerable measure because of the increasing technical activities of the Society's committees which are growing in number and extending their work into many new fields. Full details of the meeting have been given in the ASTM BULLETIN and the Summary of Proceedings, but it is appropriate to note the outstanding Symposium on Colorimetry and Photo-

A.S.T.M. MEETINGS JUNE, 1944—MAY, 1945, INCL.

Meeting	Place	Date	Notes
Annual Meeting	New York, N. Y. Waldorf-Astoria	June 26–30, 1944	16 Technical Sessions 30 Committee Meetings (2063 attendance)
Joint Technical Meeting	Philadelphia, Pa.	November 29, 30, December 1, 1944	Sympsoium on Stress-Corrosion Cracking Special Meeting sponsored jointly by A.S.T.M. and Metals Div., A.I.M.E. Eight technical sessions, with dinner. (Attendance 350). See text.
Spring Meeting and A.S.T.M. Committee Week	Canceled		See Text
District or Local Meetings (Sponsored by Groups in Cities Indicated)	Los Angeles, Calif.	September 27, 1944	New High Strength Aluminum Alloys for Aircraft by E. H. Dix, Jr. (attendance 150)
	Philadelphia, Pa.	October 12, 1944	Calculated Jominy Hardenability, by Joseph Field; The Development of Hardenability Bands, by Luther C. Boyd; The Selection of Automotive Steel on the Basis of Hardenability, by A. L. Boegehold. (attendance 250)
	Pittsburgh, Pa.	October 26, 1944	Portland Cement and the Distinctive Characteristics of the Five Different Standardized Types, by P. H. Bates; and Glass—A Summary of Its Development as an Art and as a Science[a] by F. C.Flint. (attendance 85)
	Detroit, Mich.	November 21, 1944	Life Testing of: Tire Cord, by W. E. Roseveare; Metals[b], by R. E. Peterson; Lubricating Oil[a], by H. C. Mougey. (attendance 350)
	New York, N. Y.	January 17, 1945	Processing Materials from Petroleum,[c] by J. C. Dean; film "Big Inch" (attendance over 500)
	Philadelphia, Pa.	January 22, 1945	Symposium on Magnetic Particle Testing[d] two technical sessions; informal dinner (attendance 400 and 500 respectively)
	Chicago, Ill.	January 26, 1945	Processing Materials from Petroleum, by J. C. Dean; Notes on the National Bureau of Standards, P. H. Bates. (attendance 100)
	New York, N. Y.	January 30, 1945	War Production Conference. District participated in arrangements for conference, panels and dinner. (attendance 1200)
	San Francisco, Calif.	March 15, 1945	A.S.T.M. Guest of San Francisco Chapter American Welding Society (attendance 165)
	Buffalo, N. Y.	March 28, 1945	Two sessions; informal dinner; Castings vs. Forgings vs. Welding, by N. L. Mochel; Future Trends in Aviation, by C. C. Furnas; Side Lights on the Bureau of Standards Activities, by P. H. Bates; and Developments in the American Society for Testing Materials, by C. L. Warwick. (attendance 100 at each session)
	Cleveland, Ohio	March 29, 1945	Technical session, speakers Messrs. Mochel, Bates, Warwick; same topics as Buffalo, see above. (attendance 100)
	Chicago, Ill.	March 29, 1945	War Production Conference. District sponsored panel on Nondestructive Testing, with three technical papers.[e] (attendance 200)

A.S.T.M. MEETINGS JUNE, 1944—MAY, 1945, INCL.—(*Concluded*)

Meeting	Place	Date	Notes
District or Local Meetings (Sponsored by Groups in Cities Indicated)—*Cont.*	Philadelphia, Pa.	April 12, 1945	Experimental Stress Analysis. Two sessions; C. H. Gibbons, Strain Gages; H. R. Gordon, Structural Trends Dictated by High Speed; J. O. Almen, Effect of Residual Stresses. (attendance over 200 at each session)
	Philadelphia, Pa.	May 17, 1945	Popular Night. Film and lecture on Colloids, by L. Drew Betz; plus six sound films (Army and Navy releases). (attendance 185)

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[a] Published in ASTM BULLETIN, No. 132, January, 1945.
[b] Published in ASTM BULLETIN No. 133, March, 1945.
[c] Published in *Chemical and Engineering News*, Am. Chemical Soc., Vol. 23, p. 1164, July 10, 1945.
[d] To be issued as a separate publication.
[e] Extended abstracts published in ASTM BULLETIN, No. 134, May, 1945.

metry, a notable Edgar Marburg Lecture by Dr. Harold DeWitt Smith on "Textile Fibers—An Engineering Approach to an Understanding of Their Properties and Utilization" and an address on "Minerals in War and Peace" by Dr. C. K. Leith.

The very large attendance at the 1944 Annual Meeting, plus the large number of technical committee meetings and sessions, taxed the hotel facilities greatly. If these meetings continue to grow in extent, problems of suitable accommodations will be acute, particularly in a year when an Exhibit of Testing Apparatus and Related Equipment might be held.

Joint A.I.M.E.-A.S.T.M. Technical Meeting.—A Symposium on Stress-Corrosion Cracking comprising eight technical sessions with 30 technical papers featured a three-day meeting held in Philadelphia, November 30 and 31, and December 1, 1944. The event was sponsored jointly by A.S.T.M. and the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers. Many of the papers were preprinted and distributed in advance to members of both societies, and a most extensive publication comprising the symposium papers and discussion is in preparation, to be issued shortly. During the three-day meeting, the A.S.T.M. Philadelphia District Committee, jointly with the Philadelphia A.I.M.E. section, sponsored an informal dinner, with an interesting address by Ralph Kelley, President, The Baldwin Locomotive Works, speaking on "How Do Things Look Today and for the Future" and a pertinent technical address by E. H. Dix, Jr., Aluminum Company of America, covering "Critical Discussion of Stress-Corrosion Cracking."

1945 Spring and Annual Meetings:

After consultation with the Washington Committee on Conventions and the Office of Defense Transportation, it was deemed advisable in the interest of the war effort to cancel A.S.T.M. Committee Week scheduled for February 28-March 2 in Pittsburgh, and to postpone the Spring Meeting which would have featured an interesting technical Symposium on Corrosion Prevention. This was scheduled for February 28. After consultation with the authors, it was decided to hold the symposium later if possible.

Since the war emergency has necessitated the continuance of restrictions on travel and conventions, the Executive Committee decided to limit the annual meeting to one session devoted only to the absolutely necessary business of the Society. By holding such a meeting in New York City where there is a large concentration of membership, a quorum for business can be obtained and the meeting held within the restrictions imposed by ODT. The members were accordingly advised that the annual meeting would be held on the afternoon of Wednesday, June 27 at the Hotel Pennsylvania, New York City; and the meetings planned for Buffalo, including technical sessions, the presentation and discussion of reports and papers and the holding of the Exhibit of Testing Apparatus and Equipment, were cancelled. All reports and papers scheduled for the program will be preprinted and distributed as usual, and arrangements will be made for the presentation and discussion of selected papers at district meetings during the year.

Publications:

The publication activities of the Society for 1944 were extremely heavy, due in part to the publication of the Book of A.S.T.M. Standards in that year instead of 1945 as originally scheduled. This was necessitated by the unprecedented demand for standards occasioned by the war effort, which was so great that the supply of the 1942 edition expected to last until the end of 1945 was exhausted before the close of 1944. Statistics regarding the size and number of copies printed of the three parts of the Book of Standards appear below, but it is significant to note that in the two years that elapsed between the 1942 and 1944 editions the increase in the number of standards and tentative standards in the two books was from 1070 to 1235; the increase in the total number of pages in the two editions was from 4906 to 6042, or approximately 25 per cent increase in size.

Below are listed the regular 1944 publications distributed to the members:

1944 *Proceedings*, 1139 pages, 5850 copies. Publication seriously delayed, being completed in June, 1945. In addition, preprints of reports and papers totaled 1097 pages, 2000 copies.

1944 Book of A.S.T.M. Standards:
  Part I, 2097 pages, 10,400 copies
  Part II, 1693 pages, 8200 copies
  Part III, 2252 pages, 8100 copies

Supplement to A.S.T.M. Methods of Chemical Analysis of Metals, four separate standards, aggregating 20 pages, 4000 copies. Published February, 1945.

Index to 1944 Standards and Tentative Standards, 218 pages, 19,000 copies. Published June, 1945.

Year Book, 408 pages, 4600 copies.

ASTM BULLETIN, six issues, 464 pages, average edition 7600.

Special compilations of standards published during 1944 and the first five months of 1945 are as follows:

A.S.T.M. Specifications for Steel Piping Materials (Committee A-1), 46 standards, 345 pages, 1700 copies.

Supplement to A.S.T.M. Standards on Electrical-Heating and Resistance Alloys (Committee B-4), 4 standards, 16 pages, 350 copies.

A.S.T.M. Standards on Copper and Copper Alloys (Committee B-5), 92 standards, 441 pages, 1200 copies.

A.S.T.M. Standards on Cement (Committee C-1), 20 standards, 175 pages, 2000 copies.

A.S.T.M. Standards on Mineral Aggregates (Committees C-9 and D-4), 44 standards, 120 pages, 1000 copies.

A.S.T.M. Standards on Petroleum Products (Committee D-2), 97 standards, 524 pages, 5700 copies.

A.S.T.M. Standards on Coal and Coke (Committee D-5), 28 standards, 132 pages, 1500 copies.

A.S.T.M. Standards on Paper and Paper Products (Committee D-6), 49 standards, 190 pages, 1500 copies.

A.S.T.M. Standards on Rubber Products (Committee D-11), 77 standards, 532 pages, 2000 copies.

A.S.T.M. Standards on Soaps and Other Detergents (Committee D-12), 30 standards, 172 pages, 1100 copies.

A.S.T.M. Standards on Textile Materials (Committee D-13), 78 standards, 488 pages, 1800 copies.

A.S.T.M. Standards on Plastics (Committee D-20), 109 standards, 538 pages, 4000 copies.

Joint Committee Report on Concrete and Concrete Aggregates (Supplement printed by A.S.T.M.), 142 pages, 1000 copies.

The following special publications were also issued:

A.S.T.M. Manual on Presentation of Data (Committee E-1), a reprint, 84 pages, 3050 copies.

Report of Committee A-5 on Corrosion of Iron and Steel, 25 pages, 800 copies.

Procedure for Testing Soils (Committee D-18), 206 pages, 2500 copies.

Supplement to the Bibliography and Abstracts on Electrical Contacts (Committee B-4) 32 pages, 1000 copies.

Paper and Paperboard—Characteristics, Nomenclature, and Significance of Tests (Committee D-6), 120 pages, 2500 copies.

Report on Standard Samples for Spectrographic Analysis, 24 pages, 1500 copies. This represented publication of the results of researches made for and released by the War Metallurgy Committee of the National Defense Research Council.

Symposium on Mildew Resistance, 42 pages, 1200 copies.

Symposium on Plastics, 206 pages, 4000 copies.

Symposium on Application of Synthetic Rubbers, 140 pages, 4000 copies.

Symposium on Colorimetry, 150 pages, 1500 copies (scheduled for publication in June, 1945).

Round Table Discussion on Organizing the Classification of Industrial Waters, 48 pages, 1000 copies (scheduled for publication in June, 1945).

Evaluation of Petroleum Products, 56 pages, 1000 copies (offset).

Supplement to X-Ray Diffraction Data Cards, 4350 cards, 470 copies (offset).

Hardenability Chart, 22,000 copies.

Viscosity Temperature Charts: Chart A, 11,200 copies; Chart C, 11,000 copies; Chart D, 9500 copies.

Particular attention is called to one of the publications in the preceding list, namely, Paper and Paperboard—Characteristics, Nomenclature, and Significance of Tests. This is one of the series of publications on significance of tests that our committees are developing. It was prepared under the direction of Committee D-6 on Paper and Paper Products, published under the editorship of R. C. Griffin, and is considered to be an outstanding publication of its kind.

Special mention should be made of the valuable publication resulting from the joint meeting of the Society and the American Institute of Mining and Metallurgical Engineers mentioned earlier in this report. The meeting comprised a Symposium on Stress-Corrosion Cracking, which contained 30 papers, 20 of which were preprinted and the remainder mimeographed in advance of the meeting. The entire symposium with discussion is in an advanced stage of preparation and is expected to be published in August, 550 pages, 2500 copies.

A statement of the volume of the principal publications for the past four years follows:

	1941, pages	1942, pages	1943, pages	1944, pages
Proceedings	1388	1225	1357	1139
Book of A.S.T.M. Standards	....	4906	....	6042
Supplements to Book of A.S.T.M. Standards	1731	....	1124	....
A.S.T.M. Methods of Chemical Analysis of Metals	....	....	331	32
Index to A.S.T.M. Standards and Tentative Standards	196	206	218	218
Year Book	336	352	374	408
Spring Meeting Symposiums	202	....	135	140
	3853	6689	3539	7979

In view of the greatly increased size of the 1944 edition of the Book of Standards, previously referred to, the list price to non-members for each part was increased from $9.00 to $10.00, and the members' price for extra copies from $6.00 to $6.50. For the same reason it was necessary to increase the annual charge to members to obtain two or all three parts of the Book of Standards, and as announced at the beginning of the year these charges were increased respectively from $1.50 and $2.50 to $3.00 and $5.00 a year.

The Executive Committee is considering a proposal that has been made that the Society undertake the preparation and publication of a book or series of books on mechanical testing of materials, that would be suitable as text and reference books for students, laboratory operators, material inspectors, and the testing profession generally.

Both the Committee on Papers and Publications and the Study Committee have given much thought to the publication problem presented by the increasing size and bulk of the Book of Standards. The loose unit system of publication is being studied as a possibility. Other suggestions that have been advanced include, first, further division of the present volumes, for example dividing Part I on Metals into two volumes covering respectively ferrous and non-ferrous metals; second, segregating the analytical methods from all non-metals standards and publishing them separately as is done in the case of methods of chemical analysis of metals. It has been pointed out that some duplication has developed in the quotation of similar or identical methods in different specifications and that such repetition may have to be avoided in the interest of keeping the size of our publications within reasonable bounds. Accordingly the Committee on Publications has been directed to continue its study of this problem and particularly to examine into the possibilities of publishing in a separate volume all the methods of chemical analysis of non-metals.

Believing that many members and other users of the Society's standards may find it convenient to bind separate reprints of standards in groupings of their own selection, all such reprints will hereafter be punched for the standard three-ring binder. Consideration is being given to the desirability of the Society maintaining a stock of a suitably marked binder of good quality to be furnished on order to users of A.S.T.M. standards who may wish to have such a service. Suitable binders are not presently available but will probably soon be back on the market.

Both the Publications Committee and the Study Committee in several meetings during the year gave much consideration to the methods of publishing the technical papers and discussions, whether presented at meetings or offered for publication in the BULLETIN. The Executive Committee has agreed with a recommendation of the Study Committee that there should be a more prompt publication of technical papers and discussions to stimulate wider interest in the activities of the Society and particularly in the problems currently before the technical committees. Accordingly the following publication procedures have been instituted as an initial step towards this goal:

1. Encourage the offering of papers at any time throughout the year. Preprint papers approved by the usual procedures as soon as they become available and publish synopses together with announcements and order sheets in the ASTM BULLETIN. Schedule presentation and discussion as at present and publish the papers and discussions in a bound volume of papers or *Proceedings.*

2. Publish in the BULLETIN as well as in permanent form, possibly with preprints, such papers and discussions as are deemed to have wide interest or educational value.

3. Continue to publish in the BULLETIN those technical papers, articles and committee reports which appear to have current technical or educational value, but which do not seem to warrant separate publication or inclusion in a bound volume.

In line with these procedures the March BULLETIN contained the first separate order sheet for four preprinted papers. Furthermore to facilitate inclusion in bound *Proceedings* of certain papers published first in the BULLETIN, the format of the latter publication has been changed so that type used for BULLETIN publication can be conveniently re-made for final publication in *Proceedings.* It is intended to bring this policy of offering and publishing papers during the year prominently to the attention of the members and other prospective authors of papers, for it is realized that a process of education is necessary to break away from the long-established concept that papers for A.S.-T.M. may be offered only for the annual meeting and preprinted at the time of such meeting.

As another step in this study, the possibility of establishment of a monthly technical journal will be further explored.

Acting upon joint recommendation of the Study and Publications Committees, there is being established a Special Technical Publication Series to comprise all special technical publications of the Society (in general, material not included in the *Proceedings* and BULLETIN) and the separately published compilations of standards. All publications in this Series will be numbered serially in chronologic sequence retroactive to the organization of the Society, with each compilation of standards retaining the serial number assigned to it. The complete list of publications in the Series will be suitably published, including publication in the next five-year Index; also the index published in each annual volume of *Proceedings* will include an index of all publications issued in the Special Technical Publication Series during the year.

It has been decided to resume publication in the Year Book of a geographical distribution of the membership of the Society. Such a geographical distribution was published for some years prior to 1932, when it was discontinued for reasons of economy. Since then many of the district committees of the Society as well as other members have been urging that publication of a geographical distribution of membership be resumed, partly for the convenience of the membership generally and partly from its advantages from the standpoint of membership promotion. The method of publication has been left with decision to the Committee on Papers and Publications.

Considerable thought has been given to the use of the term "tentative standard," which some of our members have thought to be a misnomer and tending to cause confusion in legal interpretation. There seems to be conflicting opinion as to the relative status of the two "grades" of standards, that is, full standards and tentative standards. At the same time it is clear that there is need for a probationary or trial status for a proposed standard before according Society approval as standard. Accordingly, acting on a recommendation of the Study Committee, the Executive Committee is proposing the complete elimination of the word "standard" from any connection with "tentative," by discontinuing the use of the term "tentative standard" and using in its place the word "tentatives" to cover collectively tentative specifications, tentative methods, tentative definitions, and tentative recommended practices. An amendment of Article VII of the By-laws is required to make this change in nomenclature and to define "tentatives" as just stated, and such an amendment is proposed elsewhere in this report in connection with other By-laws amendments.

It has also seemed desirable at the same time to modify the note that now appears under the title of all tentative specifications, methods, etc., to read as follows:

> "These Tentative Specifications (or Methods, etc.) have been approved by the sponsoring committee and accepted by the Society in accordance with established procedures, for use pending adoption as standard. Suggestions for

revisions should be addressed to the Society at 260 South Broad Street, Philadelphia 2, Pa."

The essential purpose of this change is to accentuate the difference between a "tentative" and a "standard." At the same time the Executive Committee believes it is desirable as a matter of policy to advance tentatives to the status of standard as expeditiously as possible, although it is realized that full discretion in such matters must be given to the standing committees responsible.

Richard L. Templin Award:

The Executive Committee takes pleasure in announcing to the membership of the Society that Richard L. Templin, Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, has made a gift to the Society of $1000 to be used to establish a prize award for papers describing new testing methods and apparatus. The Executive Committee has been pleased to accept this gift and with it has established the Richard L. Templin Award for the purpose of stimulating research in the development of testing methods and apparatus, encouraging the presentation to the Society of papers describing new and useful testing procedures and apparatus, and recognizing meritorious efforts of this kind. The award will be a cash prize of $25 and a suitable certificate. Mr. Templin's gift has been invested to provide the cash prize, and the Executive Committee has added to the income account the sum of $100 to defray the cost of certificates.

Papers to be eligible for the award shall have been accepted for publication in their entirety by the Society, shall be the *bona fide* production of those who contribute them, and shall not have been previously made public nor contributed elsewhere in whole or in part. The following types of papers are eligible: Those accepted by Committee E-6 on Papers and Publications for any meeting of the Society, including papers to be included as part of committee reports; those papers presented at meetings of committees of the Society accepted by Committee E-6; and those accepted by Committee E-6 for publication in the ASTM BULLETIN. The Executive Committee has adopted other rules governing the award, including appointment annually of a Committee on Award, all of which will be announced in the August issue of the BULLETIN.

Membership:

On June 1, 1945, the membership of the Society totaled 5649, the highest figure yet reached, compared with a total of 5257 on June 1 one year ago. Statistics showing gains and losses in various classes of membership are shown in the following table:

Class of Membership	Membership		Losses				Additions		Total		
	June 1, 1944	June 1, 1945	Resignations	Dropped	Death	Transfer	Transfer	Election	Loss	Gain	Increase
Honorary	10	9	...	...	1	..	..	...	1	...	1[a]
Perpetuity	9	9	...	...	..	..	..	...	...	...	...
Sustaining	188	192	1	...	..	1	5	1	2	6	4
Company, Firm, etc.	1311	1466	22	4	..	8	11	178	34	189	155
Individual, etc.	3602	3854	96	44	31	10	33	400	181	433	252
Junior	137	119	6	5	1	30	..	24	42	24	18[a]
Total	5257	5649	125	53	33	49	49	603	260	652	392
Student	377	149	22	312	..	11	..	117	345	117	228[a]

[a] Loss.

The net gain for the year of 392 compares with 353 for the preceding year. Elections to membership were the highest in the history of the Society and numpered 603, exceeding those for the previous year by 17; losses from resignations and delinquencies were 178 compared to 201 for the preceding year. Junior Members numbered 119 and Student Members 149. A decline in the number of Junior Members of 18 and a very heavy decrease in the number of Student Members is attributable to the large number of young technologists in the Armed Services.

There has been a net increase of 4 in the number of sustaining members, bringing the total to 192. There were six new sustaining members and two losses (one from resignation, the other a transfer to a company membership). Of the six new members, five were acquired by transfer of existing company memberships and one a company which had not previously held membership in the Society. The names of the new sustaining members are as follows:

- Boeing Aircraft Co.
- California Portland Cement Co.
- Congoleum-Nairn, Inc.
- Johnson and Nephew, Ltd.
- Richard Kendall Refining Co.
- Weyerhaeuser Timber Co.

The Executive Committee expresses on behalf of the Society its thanks to these companies for their willingness to lend financial support to the Society through this form of membership.

In 1938 the Executive Committee established the plan of awarding at annual meetings certificates commemorating forty years of continuous membership in the Society. Sixty-nine such certificates have thus far been awarded and this year the following twelve companies and individuals have qualified:

- H. C. Berry
- Frank Orville Clements
- Engineers' Society of Western Pennsylvania:
  - K. F. Treschow
- Myron S. Falk
- Lawford H. Fry
- W. C. Hanna
- Marquette Cement Manufacturing Co.:
  - D. S. Colburn
- Anson Marston
- Pittsburgh Testing Laboratory:
  - A. R. Ellis
- R. H. Harry Stanger
- Worcester Polytechnic Inst.:
  - F. W. Roys
- York Ice Machinery Corp.:
  - Frank J. Allen

Since in view of the abbreviated nature of the annual meeting this year, the certificates cannot be presented there as usual, they will be mailed to the respective forty-year members with a suitable communication on behalf of the Executive Committee.

The Society has lost the following members through death:

	Date of Membership
Bamford, William Brokaw	1913
Chapman, Cloyd M.	1908
Cherry, Oscar A.	1941
Curtin, Thomas I.	1937
Davis, Charles Hollister	1929
de Forest, Alfred V.	1936
Dieckmann, George P.	1938
Dunn, William R.	1904
Fleming, Virgil R.	1914
Harvey, Fred A.	1919
Houghten, F. C.	1940
Juve, Walter H.	1937
Kennedy, John W.	1922
Lindner, Karl A.	1932
Meigs, Douglas P.	1943
Mohr, Walter W.	1940
Morehouse, W. S.	1926
Nau, Carl A.	1933
Picard, Leon Charles	1941
Porter, Horace C.	1914
Roystuart, Victor I.	1942
Saklatwalla, B. D.	1909
Sargent, Paul D.	1913
Saunders, Walter M.	1902
Snyder, Paul M.	1938
Swinden, Thomas	1937
Trevithick, Harry P.	1921
Urschel, Harold C.	1942
Waterbury, J. E.	1942
Weaver, Harry A., Jr.	1944
Webster, William Reuben	1909
Wrigley, H. W.	1941
Yost, Edgar N.	1939

In addition to the above, the following representatives of company members of the Society who had taken an active interest in the Society's affairs passed away:

C. F. Hanson, Irvington Varnish & Insulator Co.
G. T. Horton, Chicago Bridge & Iron Co.
H. L. Howe, City of Rochester, Department of Public Works
K. J. Howe, Thibout & Walker Co.
James McCormick, New Hampshire Highway Department
Thomas Midgley, Jr., Ethyl Corporation
Dennistoun Wood, Southern Pacific Co.
T. A. Wright, Lucius Pitkin, Inc.

Many of these men contributed greatly to the advancement of the Society's work both in administrative and technical activities. Among them should be mentioned Past-President Cloyd M. Chapman, C. H. Davis, A. V. de Forest, C. F. Hanson, F. A. Harvey, H. C. Porter, H. P. Trevithick, W. R. Webster and T. A. Wright. The ASTM BULLETIN has carried announcement of the activities of a number of these men, including a memorial to Mr. Chapman adopted by the Executive Committee.

Some Membership Comments.—The March BULLETIN included an article on membership with a chart showing the trends since the Society was organized. From a peak of 4417 in 1930 there was a decline for four years, with an upswing starting in 1935, which has continued to the present time. While the increased number of members particularly during the past two years has been gratifying, it is certain that many companies and large numbers of individuals concerned with activities in the field of engineering materials would derive much benefit from affiliation with the Society, and it is hoped that many of the members who have cooperated so closely in extending invitations to some of these individuals and companies will continue their membership promotion activities. It is not possible to list all those who have aided in extending the membership, but their efforts are appreciated.

Elsewhere in this report reference is made to proposed changes in the By-laws which will clarify the classes of membership and provide for an increase in the permissible number of Honorary Members.

The Executive Committee is pleased to report that former members of the Society in the liberated countries of Europe are beginning to communicate to the Society their desire to resume membership. It has been arranged that the Secretary-Treasurer will write to all such former members of record inviting them to resume their membership and offering to be of assistance in bridging the gap of technical contacts disrupted by the war.

Finances:

Report for the Fiscal Year 1944.—The annual statement of the finances of the Society follows in the report of the auditors for the fiscal year, January 1 to December 30, 1944. The report gives the balance sheet of assets and liabilities, including special and designated funds (that is, the Research Fund, Medal and Lecture Fund, and Committee Funds); statement of receipts and disbursements, which items are classified into "operating" (budgeted) and "nonoperating"; details of special funds; and investment of Society funds, both book and market values being given.

Total receipts from dues and entrance fees in 1944 were $121,373.14, an increase of approximately $10,000 over the preceding year. Receipts from sales of publications totaled $121,044.41, which was about $11,000 less than the preceding year, the latter having included the large volume of sales of the 1942 Book of Standards. The sales of special publications, compilations of standards, spring meeting papers, symposiums, etc., totaled slightly over $50,000, which was higher than ever before and indicates the extent to which the number of special publications issued by the Society has grown. Miscellaneous receipts amounted to $23,129.80, consisting principally of receipts from advertising in the ASTM Bulletin and Index to Standards, receipts from interest and dividends, and registration fees. Receipts from advertising in the Bulletin at $12,391.69 are an all-time high.

Total operating receipts were $265,547.35, topping 1943 receipts by about $3000. Operating disbursements with all current bills paid (as detailed in the auditors' report) were $249,948.51—by far the highest in the Society's history, due largely to increased staff, increased publication expense, general increases due to larger membership and expanded operations, and increased cost of the Employee's Retirement Plan. Notwithstanding, there resulted a favorable balance between operating receipts and disbursements of $15,598.94, which will be used to cushion possible operating deficits in the future and to provide for suitable expansion of the Society's work.

Attention is called to the fact that the disbursements include $2500 (approximately one-half of the entrance fees) paid into the principal of the Research Fund and $7327.91 paid towards the Employees' Retirement Plan. The latter amount includes the sum of $5424 representing premiums on "unmatched policies" paid entirely by the Society in accordance with the extension of the Retirement Plan announced in the Executive Committee's report a year ago. There is also included in disbursements the sum of $3045.75 spent on emergency alternate provisions and emergency specifications, which together with similar expenditures in preceding years brings to approximately $12,000 this direct contribution to the war effort, for it has been the exigencies of the war emergency that have necessitated this work.

Under nonoperating receipts there is recorded the sum of $1000, which is the contribution of Richard L. Templin towards the establishment of an award which is announced elsewhere in this report. In this category there is also recorded the sum of $2566 received towards an A.I.M.E.-A.S.T.M. Publication Fund. Of this sum $2500 represents the contribution of the American Institute of Mining and Metallurgical Engineers towards costs of the joint publication of the Symposium on Stress-Corrosion Cracking (referred to elsewhere in this report), which amount was matched by a similar contribution from A.S.T.M.

The auditors' report includes a statement of the financial position of the Society for the past five years. The surplus in the General Funds account, exclusive of special and designated funds, is $111,606.51, compared to $105,660.86 a year ago. As has been pointed out in previous reports, the true significance of surplus is seen only in its relation to level of operations, which can be expressed by the percentage ratio of surplus to operating disbursements. When these ratios are determined for the past six years it is seen that although the dollar value of surplus has nearly doubled in that time, the ratio of surplus to operations of the Society has increased only from 38 to 44 per cent, and that actually, in relation to our level of operations, surplus this year is slightly less than a year ago.

Attention is called to the amounts reported in the various funds under the statement of liabilities. During the fiscal year a total of $4000 was transferred from general surplus and allocated as follows: $1000 to the Headquarters Fund, $1000 to the Executive Retirement Reserve, and $2000 to the Reserve Against Depreciation in Investments.

REPORT OF THE AUDITORS FOR THE FISCAL YEAR, JANUARY 1 TO DECEMBER 30, 1944

Philadelphia, January 9, 1945.

MR. C. L. WARWICK, *Secretary-Treasurer*
AMERICAN SOCIETY FOR TESTING MATERIALS
Philadelphia, Pennsylvania

Dear Sir:

We have examined the books and accounts of your Society for the period from January 1, 1944, to December 30, 1944. We did not make a detailed audit of all transactions, but made extensive tests to determine the accuracy of your records; nor did we verify accounts receivable by correspondence with debtors.

We have prepared and submit herewith balance sheet as of December 30, 1944, statement of cash receipts and disbursements for the year ended that date, and other supporting schedules, all of which are in agreement with the records of your Society. In our opinion, these statements present fairly the financial position of the Society at December 30, 1944, and the results of its operations for the year then ended.

The investments owned by the Society as detailed herein were examined by us. All income from investments was properly accounted for.

Respectfully submitted,
JOHN HEINS & CO.
(Signed) ALFRED C. BROMBACH
Certified Public Accountant.

BALANCE SHEET AS OF DECEMBER 30, 1944

(Including Special and Designated Funds)

ASSETS

General Funds:			
Current: Cash	$81 637.45		
Less check drawn as of December 30, 1944 to cover cost of *Proceedings*, Book of Standards, and Emergency Alternate Provisions	39 000.00		
		$42 637.45	
Investments (Market Value, $114,513.12)—Cost		114 237.61	
Accounts Receivable		11 986.97	
Total Current Assets—General Funds			$168 862.03
Furniture and Fixtures (depreciated book value)			6 780.66
Total Assets General Funds			$175 642.69
Special and Designated Funds:			
Cash: A.S.T.M. Research Fund		$4 463.69	
Dudley Medal and Marburg Lecture Fund		343.43	
Committee Funds		11 884.23	
			16 691.35
Investments:			
A.S.T.M. Research Fund (Market Value, $36 471.32)—Cost		$37 408.99	
Dudley Medal and Marburg Lecture Fund (Market Value, $4786.25)—Cost		6 625.00	
Committee Funds (Market Value, $6206.88)—Cost		6 000.00	
			50 033.99
Total Assets Special and Designated Funds			$66 725.34
Total Assets			$242 368.03

LIABILITIES

General Funds:			
Current: Accounts Payable:			
Committee C-1	$169.88		
Advance Collections	8 839.27		
Total Current Liabilities—General Fund		$9 009.15	
Life Membership Fund	3 005.20		
Headquarters Fund	6 491.56		
Publication Fund	2 515.00		
Book of Standards Reserve	17 113.98		
Executive Retirement Reserve	7 555.00		
Retirement Fund Reserve	3 425.00		
Reserve against Depreciation of Investments	12 000.00		
Joint A.S.T.M.-A.I.M.E. Publication Fund	1 921.29		
Special Award Fund	1 000.00		
Surplus	111 606.51		
		166 633.54	
Total Liabilities General Funds			$175 642.69
Special and Designated Funds:			
A.S.T.M. Research Fund:			
Principal	$39 198.49		
Income	2 674.19	$41 872.68	
Dudley Medal and Marburg Lecture Fund:			
Principal	6 625.00		
Income	343.43	6 968.43	
Committee Funds, unexpended balances		17 884.23	
Total Special and Designated Funds			$66 725.34
Total Liabilities and Funds			$242 368.03

COMPARISON OF GENERAL FUNDS FOR FISCAL YEARS 1940–1944, INCLUSIVE.

At Close of Fiscal Year	Assets				Liabilities			
	Cash	Invest-ments	Accounts Receivable	Furniture and Fixtures	Accounts Payable	Reserve for Book of Standards	Miscellaneous Funds	Surplus
1940	$9 608.61	$72 568.95	$13 388.88	$6 561.93	$3 380.25	$7 890.25	$9 713.79	$81 144.08
1941	18 206.61	88 001.45	14 120.99	6 440.58	3 937.44	13 890.25	12 907.43	96 034.51
1942	14 915.67	93 281.45	6 846.09	6 362.86	5 036.28	13 890.25	17 902.43	84 577.11
1943	29 220.41	111 136.68	14 567.65	6 960.38	5 569.02	17 113.98	33 541.26	105 660.86
1944	42 637.45	114 237.61	11 986.97	6 780.66	9 009.15	17 113.98	37 913.05	111 606.51

RECEIPTS AND DISBURSEMENTS

FOR THE PERIOD ENDED DECEMBER 30, 1944

Cash balance, January 1, 1944			$29 220.41
RECEIPTS			
Operating Receipts (Budgeted):			
Dues and Entrance Fees:			
Current Dues	$111 260.87		
Past Dues	751.77		
Advance Dues	4 025.50		
Income, Life Membership Fund	150.00		
Entrance Fees	5 185.00		
Total Dues		$121 373.14	
Sale of Publications:			
Separate Standards	$7 338.55		
Book of Standards (Members additional parts)	7 708.50		
1942 Book of Standards	24 089.36		
1943 Supplements to Book of Standards	18 723.94		
1944 Book of Standards	1 672.70		
Methods of Chemical Analysis of Metals	3 056.65		
Proceedings	4 635.40		
Selected Standards for Students	2 148.10		
Bulletin Subscription (Nonmembers)	608.75		
Special Reprints and Miscellaneous	51 062.46		
Total Sale of Publications		$121 044.41	
Miscellaneous:			
Advertising, Bulletin	$12 391.69		
Advertising, Index	2 100.00		
Interest and Dividends	5 476.91		
Registration and other fees, Annual Meeting	2 091.00		
Committee A-1 Technical Assistant	921.30		
Miscellaneous	148.90		
Total Miscellaneous Items		$ 23 129.80	
Total Operating Receipts (Budgeted):		$265 547.35	
Nonoperating Receipts (Not Budgeted):			
Investments, Matured or Sold	$46 260.13		
Excess Remittances	667.30		
Committee C-1 Technical Assistant	1 800.00		
Executive Retirement Reserve	210.00		
Retirement Fund Reserve	136.05		
Special Award Fund	1 000.00		
A.S.T.M.-A.I.M.E. Publication Fund	2 566.00		
Total Nonoperating Receipts		$52 639.48	
Total Receipts			$318 186.83
Total Receipts and Cash Balance, January 1, 1944			$347 407.24

Brought Forward			$347 407.24

DISBURSEMENTS

Operating Disbursements (Budgeted):			
Publications:			
Year Book	$4 139.65		
1942 Book of Standards	1 479.46		
1944 Book of Standards	30 037.65[a]		
Emergency Alternate Provisions	3 040.75[a]		
Methods of Chemical Analysis of Metals	730.95		
Proceedings	19 056.20[a]		
Preprints	4 347.93		
Spring Meeting Papers	649.28		
ASTM Bulletin	11 044.72		
Circulars to Members	1 824.56		
Separate Standards	3 195.12		
Index to Standards and Tentative Standards	3 711.33		
Special Reprints (Symposiums, etc.) Miscellaneous	18 813.92		
Authors' Reprints, Electros, etc., at Cost	752.55		
Total Disbursements, Publications		$102 824.07	
Salaries		86 834.76	
General Office Expenses		22 332.70	
Expenses, Standing and District Committees		4 776.59	
Expenses, Meetings		6 073.29	
American Standards Assn. and Sectional Committees		1 000.00	
Traveling Expenses, Administrative and Special Committees		6 195.79	
Rent, Headquarters		8 880.48	
Furniture and Fixtures		788.95	
Principal, A.S.T.M. Research Fund		2 500.00	
Dues, Contributions, Miscellaneous		266.50	
Employees' Retirement Fund		7 327.91	
War Emergency Expense		147.47	
Total Operating Disbursements (Budgeted)		$249 948.51	
Nonoperating Disbursements (Not Budgeted):			
Investments	$48 808.75		
Refund of Excess Remittances	667.30		
Headquarters Fund	395.55		
Technical Assistant Committee C-1	1 804.97		
Joint A.S.T.M.-A.I.M.E. Publication Fund	3 144.71		
Total Nonoperating Disbursements		$54 821.28	
Total Disbursements			$304 769.79
Cash Balance, December 30, 1944			$42 637.45

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[a] These amounts include a check for $39,000 drawn against the cost of the 1944 Book of Standards, Emergency Alternate Provisions, and the 1944 *Proceedings*, but not actually paid on December 31, 1944.

In addition to the general funds of the Society, the Secretary-Treasurer has on hand the following funds:

A.S.T.M. RESEARCH FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance January 1, 1944	$35 496.82	$33 757.93	$1 738.89
Receipts:			
Contribution—A.S.T.M. Current Entrance Fees	+2 500.00		+2 500.00
Sale of Securities	+1 201.67	−7 464.03	+8 665.70
	$39 198.49	$26 293.90	$12 904.59
Disbursements:			
Purchase of Securities		+11 115.09	−11 115.09
Balance, December 30, 1944	$39 198.49	$37 408.99	$1 789.50
Income Account:			
Balance, January 1, 1944	$1 431.89		
Receipts:			
Interest and Dividends on Investments	1 343.34		$2 775.23
Disbursements:			
Committee B-8 on Electrodeposited Metallic Coatings	100.00		
Miscellaneous (Sale of Securities)	1.04		101.04
Cash Balance, December 30, 1944			$2 674.19

DUDLEY MEDAL AND MARBURG LECTURE FUND

Balance, January 1, 1944			
Principal—Investments (at cost)	$6 625.00		
Income—Cash	519.18	$7 144.18	
Receipts			
Interest on Investments		66.00	$7 210.18
Disbursements			
Engrossing 1944 Lecture Certificates	$3.25		
Honorarium 1944 Lecture	200.00		
Cost of 1944 Medal	38.50		241.75
			$6 968.43
Balance, December 30, 1944:			
Principal—Investments (at cost)		$6 625.00	
Income—Cash		343.43	$6 968.43

COMMITTEE FUNDS

Committee A-1 on Steel	$949.69		
Committee A-5 on Corrosion of Iron and Steel	3 147.55		
Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys	2 975.47		
Committee B-6 on Die-Cast Metals and Alloys	2 500.00		
Committee B-8 on Electrodeposited Metallic Coatings	45.36		
Committee C-1 on Cement	832.76		
Committee C-1—Cement Reference Laboratory	700.00		
Committee C-9 on Concrete and Concrete Aggregates	200.82		
Committee C-9—Sanford E. Thompson Medal Fund	394.25		
Committee C-15 on Manufactured Masonry Units	358.56		
Committee C-18 on Natural Building Stones and Slate	174.86		
Committee D-1 on Paint, Varnish, Lacquer, and Related Products	74.25		
Committee D-2 on Petroleum Products and Lubricants	123.37		
Committee D-5 on Coal and Coke	1 326.77		
Committee D-12 on Soaps and Other Detergents	73.30		
Committee D-13 on Textile Materials	608.87		
Committee D-13—Testing Textile Finishes	238.34		
A.S.A. Sectional Committee on Specifications for Cast-Iron Pipe and Special Castings	1 739.27		
Research Committee on Fatigue of Metals	218.06		
Detroit District Committee	1 098.81		
Pittsburgh District Committee	55.50		
Phila. District Committee	48.37		
Total Committee Funds		$17 884.23	
Accounted for as follows:			
Cash Balance, December 30, 1944		$11 884.23	
Investments—at cost		6 000.00	
			$17 884.23

INVESTMENTS

AS OF DECEMBER 30, 1944

GENERAL FUNDS

Number of Shares or Par Value		*Cost or Book Value*	*Market Value*
	Bonds		
$2 000	Associated Electric Co., 4½'s, due 1953	$1 693.50	$1 850.00
2 000	Columbia Gas & Electric Co., Debentures 5's, due 1961	2 025.34	2 075.00
4 000	Erie R. R. Co. Income, 4½'s, due 2015	2 832.00	3 520.00
4 000	General Steel Cast. Corp., First Mortgage Series A, 5½'s due 1949	3 610.00	4 240.00
2 000	Pressed Steel Car Co. Inc., 15-yr. Debentures, 5's, due 1951	1 912.50	2 025.00
3 000	Southern Pacific Debentures, 4½'s, due 1969	2 544.75	2 775.00
13 000	U. S. Defense Savings Bonds, Series G, 2½ per cent[a]	13 000.00	12 496.00
3 800	U. S. Treasury Bonds, 2½'s,due 1967–72	3 800.00	3 827.30
4 000	U. S. Treasury Bonds, 2½'s, due 1964–69	4 000.00	4 013.75
3 000	U. S. Treasury Bonds, 2½'s, due 1965–70	3 000.00	3 009.38
7 000	U. S. Certificates of Indebtedness, February, 1945, ⅞ per cent[b]	7 000.00	7 002.45
2 000	U. S. Treasury Bonds, 2 per cent, due 1952–54	2 000.00	2 008.75
22 000	U. S. Treasury Notes, 1¼'s, March, 1947	22 000.00	22 048.12
		$69 418.09	$70 890.75
	Stock		
30	Allis-Chalmers Mfg. Co., 4 per cent preferred	$3 316.20	$3 420.00
25	American Can Co., common	2 122.30	2 250.00
19	American Cyanamid Co., 5 per cent Cumulative preference[b]	190.00	211.37
50	American Cyanamid Co., Class B common	1 764.25	1 950.00
100	American Radiator & Std. Sanitary Corp., common	1 564.32	1 175.00
25	American Tobacco Co., common	2 110.12	1 625.00
100	Atlantic Refining Co., common par value $25	2 302.50	3 100.00
25	Colgate-Palmolive-Peet Co., $4.25 preferred	2 525.00	2 662.50
10	Delaware Power & Light Co., common[b]	135.00	161.25
50	General Telephone Corp., $2.50 preferred[b]	2 675.00	2 637.50
25	Hazel Atlas Glass Co.	2 510.64	2 775.00
100	S. S. Kresge Co., common	2 490.18	2 725.00
100	Mathieson Alkali Works, common, no par value	3 016.00	2 375.00
20	G. C. Murphy Co., 4¾ per cent preferred	2 100.00	2 320.00
25	J. C. Penney Co., common	2 279.63	2 712.50
67	Philadelphia Electric Co., common[a]	1 185.06	1 407.00
116	Public Service Corp. of N. J., common	4 369.50	1 986.50
50	Sperry Corp., common	1 510.00	1 418.75
50	The Texas Company	2 519.55	2 450.00
20	United Gas Improvement Co., common	315.00	285.00
50	U. S. Gypsum, common	3 819.27	3 975.00
		$44 819.52	$43 622.37
		$114 237.61	$114 513.12

A.S.T.M. RESEARCH FUND

Number of Shares or Par Value		*Cost or Book Value*	*Market Value*
	Bonds		
$2 000	First Mortgage Real Estate, 1315–17 Spruce St., 6's, due 1945	$2 000.00	$830.00
2 000	Associated Electric Co., 4½'s, due 1953	1 693.50	1 850.00
1 500	Balto. & Ohio R. R. General & Refunding, 5's, Series F., due 1996	1 511.25	1 095.00
2 000	Columbia Gas & Electric Co., Debentures, 5's, due 1961	2 025.31	2 075.00
4 500	U. S. Defense Savings Bonds, series G, 2½ per cent[a]	4 500.00	4 321.50
2 000	U. S. Treasury Bonds, 1965–70, 2½'s	2 000.00	2 006.25
3 000	U. S. Treasury Notes, 1¼'s, March, 1947	3 000.00	3 006.56
		$16 730.06	$15 184.31
	Stock		
40	Allis-Chalmers Mfg. Co., 4 per cent preferred	$4 421.59	$4 560.00
12	Consolidated Edison Co. of N. Y., $5 preferred	1 234.39	1 296.00
29	Consumers Power Co., $4.50 preferred, no par value	2 914.50	3 190.00
5	Delaware Power & Light Co., common[b]	67.50	80.63
98	General Motors Corp., common, par value $10[c]	6 504.75	6 272.00
30	G. C. Murphy Co., 4¾ per cent preferred	3 150.00	3 480.00
33	Philadelphia Electric Co., common	583.70	693.00
9	Public Service Corp. of N. J., common	135.00	154.13
50	Sperry Corp., common	1 510.00	1 418.75
10	United Gas Improvement Co., common	157.50	142.50
		$20 678.93	$21 287.01
		$37 408.99	$36 471.32

DUDLEY MEDAL & MARBURG LECTURE FUND

500	Balto. & Ohio. R. R. Refunding & General Mortgage, 6's, Series C, due 1995	$550.00	$406.25
6 000	Balto. & Ohio. R. R. Refunding & General Mortgage 5's Series A, due 1995	6 075.00	4 380.00
		$6 625.00	$4 786.25

COMMITTEE FUNDS

5 000	U. S. Treasury Bonds, 2¾'s, 1947–45	5 000.00	5 079.69
1 000	U. S. Treasury Bonds, 2⅞'s, 1960–55	1 000.00	1 127.19
		$6 000.00	$6 206.88
	Grand Total	$164 271.63	$161 977.57

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[a] Market value is stated at redemption value as of December 30, 1944.

[b] Market values were taken from current financial publications with the exception of quotations on inactive or unlisted securities indicated by footnote a. These values were obtained from brokers as of December 30, 1944.

[c] The income from these shares is, by agreement, paid to an annuitant.

As previously noted $2500 was taken from the Publication Fund as our contribution to the joint A.I.M.E.-A.S.T.M. Publication Fund.

Investments of Society funds as of December 30, 1944, are given in the auditors report, both book and market values being shown. The following changes during the fiscal year in the investment portfolio are noted:

GENERAL FUNDS

Bought		Cost
$2 000	Associated Electric Co. Bonds, 4½s, 1953	$1 693.50
4 000	Erie Railroad Co. Income Bonds 4½s, 2015	2 832.00
3 000	Southern Pacific deb. Bonds 4½s, 1969	2 544.75
3 000	U. S. Treasury Bonds, 2½%, 1965–70	3 000.00
22 000	U. S. Treasury Notes 1¼%, March 1947	22 000.00
7 000	U. S. Certificates of Indebtedness ⅞%, Feb. 1945	7 000.00
2 000	U. S. Treasury Bonds, 2%, 1952–54	2 000.00
30	shares Allis-Chalmers Mfg. Co. 4% Pfd.	3 316.20
		$44 386.45

Sold, Called or Matured		Received
$8 000	U. S. Treasury Certificates of Indebtedness (matured)	$8 000.00
3 000	Armour & Co. of Del. C 4s, 1957 (called)	3 125.00
9 000	Baltimore & Ohio RR Bonds F 5s, 1996 (sold)	4 673.80
500	Florida Power & Light Co. Bonds 5s, 1954 (called)	507.50
3 000	Michigan Cons. Gas Co. Bonds 4s, 1963 (called)	3 120.00
1 000	Pressed Steel Car Co. 5s, 1951 (called)	1 000.00
50	shares Great Northern Ry. Co. Pfd. (sold)	1 783.91
100	shares Borden Co. (sold)	3 261.49
100	shares Philco Corp. (sold)	3 424.30
25	shares Sears, Roebuck Co. (sold)	2 360.26
100	shares Westinghouse Elec. Corp. (sold)	10 582.28
		$41 838.54

RESEARCH FUND

Bought		Cost
$2 000	Associated Electric Co. Bonds 4½s, 1953	$1 693.50
2 000	U. S. Treasury Bonds 2½s, 1965–70	2 000.00
3 000	U. S. Treasury Notes 1¼%, March 1947	3 000.00
40	shares Allis-Chalmers Mfg. Co. 4% Pfd.	4 421.59
		$11 115.09

Sold, Called or Matured		Received
$1 500	Florida Power & Light Co. Bonds 5s, 1954 (called)	$1 522.50
3 000	Republic Steel Corp. Bonds B 4½, 1961 (called)	3 120.00
25	shares Pittsburgh Plate Glass Co. (sold)	2 983.20
1 000	Allis-Chalmers Mfg. Co. 4s, 1952 (called)	1 040.00
		$8 665.70

In the General Funds, profits on securities sold, called or matured totaled $5136.08, whereas losses on sale and conversion of securities (principally Baltimore and Ohio Bonds) totaled $4583.06 or a net gain of $553.02. In the Research Fund there was a net profit in sale of securities of $1201.67.

No account has been taken in the accompanying financial statement of the assets of the Society in the form of publications in stock. An inventory of technical publications as of June 1, 1945, may be summarized as follows:

		Number of Copies
Year Book		516
Proceedings		4 030
Index to Proceedings, 6 parts, total		1 482
1944 Book of A.S.T.M. Standards:		
Part I	2942	
Part II	2377	
Part III	2092	7 411
Methods of Chemical Analysis of Metals		548
Selected Standards for Students in Engineering		2 295
X-Ray Diffraction Data	sets	507
Reprints of Standards (approximate)		100 000
Special Reprints (approximate)		45 000

1945 Finances.—The Society's operations for 1945 are based on current operating receipts of $290,000, to which has been added from surplus for current operations the sum of $7000, bringing the total of budgeted receipts to $297,000. Receipts from dues and entrance fees are estimated at $125,000; receipts from sales of publications at $142,000, which includes an estimate of $62,000 from sales of the 1944 Book of Standards; miscellaneous receipts, including advertising, interest and dividends, are estimated at $23,000. Disbursements have been estimated at $297,000, which provides fully for the normal operating expenses of the Society, including all current publications, emergency specifications, all meetings and committee activities, and the Employees' Retirement Fund, as well as for certain expansion of the Society's staff. A contingency item larger than in previous years is provided because of more than usual uncertainty with respect to some of our activities, particularly publications.

In estimating the cost of publications there has been uncertainty as to the date of publication of the next edition of the Book of Standards. For budgeting purposes the assumption has been made that re-publication of this volume will be in 1947, that is, resuming the triennial period of publication, and for this purpose a reserve of $15,000 has been budgeted from current income against the cost of the next edition. Should the demand for the 1944 edition be so great as to exhaust the supply in 1946, that condition itself should provide added income with which to meet the increased expense of a final publication.

The Executive Committee reviews the budget of receipts and disbursements quarterly and makes any adjustments that may be necessary.

Since January 1, 1945, securities have been sold or matured yielding $10,756, and investments have been made in the sum of $55,855.63, including $50,000 of current funds temporarily invested in U. S. Treasury Bonds 2%, 1952–54. The total book value of Society investments as of May 31, 1945, in all funds was $208,107.23. The market value of these securities on the same date was $215,103.55. The Society's cash balance on May 31, 1945, was $153,331.34.

Retirement Plan for Employees:

There have been no developments of importance in the Retirement Plan for Employees since the substantial augmentation of the Plan in May of 1944, as reported to the Society by the Executive Committee a year ago. In the past year three additional employees have entered the Plan, bringing the total number of participants to 21 of the 25 eligible employees. The remaining six employees of the Society are not yet eligible, having been with the Society less than one year.

The Society's total contribution in premiums for retirement policies for the above mentioned 21 employees is at the annual rate of approximately $8150, which is roughly 8½ per cent of the present salary roll and 2¾ per cent of estimated current disbursements. The total of employees' annual contributions, including insurance benefits which most of them have elected, is approximately $2340.

Cooperative Activities:

The Society's cooperative relations with other organizations have been continued along lines of well-established policy. One of the most important developments is the establishment of a small joint committee with the Federation of Paint and Varnish Production Clubs to consider the relationships of the Society and the Federation in their common interest in the development of standard specifications and methods in the paint field. The Executive Committee has appointed three members of the Society selected from the membership of Committee D-1 on Paint, Varnish, Lacquer, and Related Products to serve on the joint committee, namely, R. D. Bonney, chairman, H. A. Nelson, and C. H. Rose. The joint committee reviews methods of test presented to it either by Committee D-1 or the Federation and the recommendations of the joint committee are transmitted to the two organizations. The formation of the committee has already facilitated contacts between subcommittees or other groups in each organization working on similar problems and it is planned that through the joint committee the Federation will bring to the attention of Committee D-1 the need for test methods upon which Committee D-1 should put some study.

The Society's cooperative work with the Society of Automotive Engineers has continued in various fields, notably those of rubber, steel, and the nonferrous metals. In the case of steel a closer tie-in has been effected by formal representation of the Society on the Iron and Steel Division of S.A.E. through the appointment of N. L. Mochel, chairman of Committee A-1 on Steel, as representative, with R. J. Painter, Assistant to the Secretary of the Society, as alternate. At the same time the S.A.E. has been given official representation on the Advisory Committee of Committee A-1 through the designation of F. P. Gilligan as member with R. S. Burnett as alternate. In this way the two societies can keep closely in touch with each other on important developments in their respective activities in the field of steel specifications.

The Plastic Materials Manufacturers Association has invited the cooperation of the Society in the development of their research program on properties of plastic materials, and Committee E-9 on Research has designated Robert Burns, chairman of Committee D-20 on Plastics, as the Society's representative to work with the P.M.M.A. in the development of this program.

R. J. Moore has been appointed to represent the Society on the Division of Engineering and Industrial Research of the National Research Council, succeeding T. S. Fuller.

The Society has accepted an invitation to be represented on the Advisory Committee of the Testing Division of the Technical Association of the Pulp and Paper Industry to further facilitate the cooperative relations between A.S.T.M. and TAPPI in the development of tests and specifications for paper. L. S. Reid, chairman of Committee D-6 on Paper and Paper Products, has been designated as the Society's representative.

Cooperation of committees of the Society with the various departments of the Government in the development of Federal specifications and of various departmental specifications such as those of the Armed Services is one of the important phases of our cooperative work with other bodies. The development in the past year of joint Army-Navy (JAN) specifications designed to simplify and speed up procurement of war materiel by the Armed Services is of particular interest to those committees of the Society engaged in fields where the JAN specification work has been initiated. The Executive Committee has been discussing informally, with Government officials responsible for these activities, the establishment of procedures whereby the Society can render a more effective service to the Government in the development of Federal and JAN specifications, especially in the elimination of conflicting requirements in tests and specifications for materials and products that are produced for both military and industrial applications. Several informal conferences have been held preparatory to more formal consideration of the whole subject.

American Standards Association:

The Executive Committee has devoted much attention during the past year to a number of important questions of policy of rather fundamental nature touching the relationships between the Society and the American Standards Association. Discussions of questions summarized in the report a year ago have been continued and brief comment regarding some of the matters is justified here.

The Executive Committee has taken the position on behalf of the Society that a strong American Standards Association is desirable to coordinate and foster cooperation in the writing of national standards and to be the voice of the American standardizing bodies in international standardization, but that the American Standards Association should not formulate standards nor compete with its member bodies in the formulation and promulgation of standards. In the opinion of the Executive Committee there has been recently an undesirable trend towards the establishment of the American Standards Association as a more or less autonomous body rather than a federation or association of the national standardizing bodies constituting the "Member Bodies" of A.S.A. The Executive Committee believes that such a trend is contrary to the best interests of the standardization movement in this country as well as to the best interests of the A.S.A. itself, and it has accordingly made a strong presentation of this view to the officers of the Association.

One way in which the Executive Committee believes this trend has been manifested is in a proposal that has been advanced for the incorporation of the American Standards Association through a Federal Charter. Study of a proposed Act of Congress thus to incorporate the A.S.A. has led the Executive Committee strongly to oppose such incorporation under the particular terms proposed. The views of the Executive Committee were expressed recently in a communication to the President of A.S.A. and at a meeting of the Standards Council, accompanied by a request that no action should be taken in the matter of Federal incorporation until the subject had been formally considered by all the member bodies at a conference of member bodies' representatives called for that purpose. It is understood that such a meeting will be held.

The Executive Committee voted affirmatively for the Society on certain amendments of the Constitution of the American Standards Association, expressing at the same time a strong preference for an alternative method of stating the basic principle or concept of operation of the Association. The most significant amendment of the Constitution dealt with the broadening of the scope of the Association to cover standardization in other fields than those strictly engineering, which was accomplished by the elimination of the phrase "in those fields in which engineering methods apply" from the statement of Objects.

An understanding has been reached with the A.S.A. regarding the manner in which the A.S.A. will hereafter refer in its publications, minutes, correspondence and other literature to an A.S.T.M. standard that has been approved as an American Standard. At our request the Association is changing its practice so that hereafter the A.S.T.M. title and designation will be given first, followed by the designation of the American Standard by the A.S.A., thus: American Standard Specifications for Hard-Drawn Copper Wire (A.S.T.M. B1-40; ASA H4.2-1941).

The Board of Directors of A.S.A. has established a Conference of Staff Executives of Member Bodies and Associate Members of A.S.A. for the primary purposes of promoting better understanding among association executives of the American standardization movement and of the purposes, organization, policies and procedures of A.S.A.; providing a means for such staff executives to discuss matters of mutual interest to A.S.A. and its member bodies; and also making available to the Board and officers of the Association a group whose advice on request might be helpful to the advancement of A.S.A. The Conference is authorized to conduct forums for discussion of standardization problems and activities of broad national significance. In order to implement the formation of this Conference and to carry on its activities, a Conference Executive Committee of nine members has been appointed. The Secretary-Treasurer of the Society has been designated as chairman of this committee. A more complete announcement appears in the May BULLETIN.

An announcement has appeared in the public press and elsewhere[4] of a conference of industrial executives called for the Secretary of Commerce by the Visiting Committee of the National Bureau of Standards, for the purpose of making recommendations to the Secretary in regard to the relative rôles that should be played by the Department of Commerce and industry in post-war standardization activities. A committee of the conference under the chairmanship of Charles E. Wilson, President of the General Electric Co., is preparing a report of the conference to be submitted to the Secretary of Commerce, but as yet nothing has been officially released regarding such report. The significance and importance of this subject in relation to standardization work, and hence to the activities of the Society, are obvious and the Executive Committee will closely follow developments from this conference.

H. H. Morgan has been elected on the nomination of the Society as a member of the Board of Directors of A.S.A. for a term of three years beginning January 1, 1945. With his election to the Board, Mr. Morgan resigned as one of the Society's representatives on the Standards Council and J. R. Townsend was named to succeed him. R. E. Hess, Assistant Secretary of the Society, continues as alternate.

A. G. Ashcroft has been re-appointed as the Society's representative on the Advisory Committee on Ultimate Consumer Goods; and J. R. Townsend has succeeded H. H. Morgan as the Society's representative on the Mechanical Standards Committee.

International Standardization Activities:

Reference was made in the report a year ago to the intended formation of a United Nations Standards Coordinating Committee with the primary objectives of promoting the maximum possible coordination of the work of the national standards associations in the United Nations and the unification of standards necessary for the war effort and the immediate post-war period. The following united nations, through their respective standards associations, have joined the Committee:

Australia
Brazil
Canada
China
Great Britain
New Zealand
South Africa
United States

The national standardizing agencies of Russia and Mexico are considering membership in the UNSCC.

Two staff offices have been established, one in London and the other in New York City, which cooperate as a single central office. The New York office represents the standards associations of the following nations: Brazil, Canada, China, Mexico, and United States.

The American Standards Association represents the United States in the United Nations Standards Coordinating Committee and is responsible for developing the United States viewpoint with respect to initiating international discussions looking toward the harmonization of national standards. Proposals may originate in any of the individual countries. An A.S.A. Reviewing Committee has been named for the purpose of considering the desirability of holding international discussions on any project. J. R. Townsend, one of the Society's representatives on A.S.A. Standards Council, is serving on this committee. A number of standardization projects of interest to the Society have been

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Industrial Standardization, February, 1945, Part I.

proposed, among them being the standardization of grades of shellac and methods of testing, definitions of terms relating to heat treatment of metals, methods of testing textiles, methods of expressing moisture content of wool knitting yarns, definition of rayon, terms used in the plastics industry, building materials, etc. The Society has been asked to solicit opinions with respect to undertaking several of these projects and, it is expected, will be named to assume leadership for the development of some of them.

The Executive Committee plans to delegate authority to the Administrative Committee on Standards (E-10) to consider and act on all proposals for A.S.T.M. participation in UNSCC projects, dealing directly with the individual standing committees of the Society and reporting periodically to the Executive Committee on all developments.

The work in promotion of Inter-American Standards that has been carried on through a department of the American Standards Association has been continuing, although it is understood that the financial support given to this work by the Office of Inter-American Affairs of the Government was discontinued at the close of 1944 so that further financial support must come from industry. Interest in standardization activities in the Latin-American countries has greatly increased in recent years. Argentina has long had its own standardizing body, IRAM; in 1941 Brazil organized its own association. The Instituto Uruguayo de Normas Técnicas was formed in Uruguay in 1942; Mexico organized its Department of National Standards in 1943; and in 1942 a National Technological and Standardizing Institute was formed at the University of Chile. The interest of Latin-American countries in A.S.T.M. standards continues to be active and many of our publications go to the standardizing bodies and engineers in those countries.

A proposal to form a Pan-American Committee on Technical Standards has been made by the Brazilian Standards Association and is under consideration.

The Society has been lending such assistance as it can to the National Resources Commission of China, both through its Technical Office in this country (which Office has acquired a membership in the Society) and through the American Mission to China headed by Mr. Donald Nelson and Mr. Howard Coonley. A number of publications, including both the 1942 and 1944 Books of Standards, have been made available to the Commission. The Society has also furnished publications and information about its work to Major E. K. Smith and Mr. Dickson Reck who are now in Chungking as liaison officers to the National Resources Commission of China assigned by the State Department. The Chinese Bureau of Weights and Measures has also resumed its membership in the Society and an endeavor will be made when improved shipping facilities are available to supply the Chinese Government through these agencies with certain recent technical publications that will be of particular value to China both in its war effort and in the post-war period.

Respectfully submitted on behalf of the Executive Committee,

P. H. BATES,
President.

C. L. WARWICK,
Secretary-Treasurer.
June 27, 1945.

REPORT OF COMMITTEE A-2

ON

WROUGHT IRON*

Although Committee A-2 on Wrought Iron has not held any meeting during the past year, it has furthered some of its work by correspondence and is presenting one recommendation to the Society at this time.

The membership of the committee now totals 47, of whom 15 are classified as producers, 26 as consumers, and 6 as general interest members.

REVISION OF STANDARD, IMMEDIATE ADOPTION

At the suggestion of the pipe committee of the American Iron and Steel Institute, action was taken on a revision of the Standard Specifications for Wrought Iron Pipe (A 72 – 39). This revision deals largely with the harmonizing of Specifications A 72 with the Standard Specifications for Welded and Seamless Steel Pipe (A 53 – 44) as regards their general scope and covering particularly the addition of provisions for galvanizing wrought iron pipe including the applicable test methods. The revised specifications[1] have been approved by letter ballot by Subcommittee I on Tubes and Pipe (E. B. Story, chairman). The committee accordingly recommends this revision for immediate adoption and accordingly asks for the necessary nine-tenths vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

This recommendation has been submitted to letter ballot of the committee which consists of 47 members; 43 members returned their ballots, of whom 37 have voted affirmatively, 0 negatively, and 6 members marked their ballots "not voting."

Respectfully submitted on behalf of the committee,

C. B. BRYANT,
Chairman.

JAMES ASTON,
Secretary.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] These revised specifications were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE A-5

ON

CORROSION OF IRON AND STEEL*

This report of Committee A-5 on Corrosion of Iron and Steel presents only the reports of its subcommittees engaged in making periodic inspections of black sheet, galvanized sheet, and wire and wire products exposed to outdoor weathering. The other subcommittees of Committee A-5—those responsible for the development of methods of testing metallic coatings and the writing of specifications—have completed very little work because of circumstances preventing coming together for meetings.

An editorial change is being made in the Standard Method of Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron or Steel Articles (A 239 – 41). In Section 1 on Scope the reference to "pipe and tubing" is being replaced by "electrical metallic tubing and rigid conduit pipe." This change is desirable to clarify the original intent of the scope section. The Preece test is not usually applied to hot galvanized pipe (a commodity of the deleted "pipe and tubing" class) which is furnished in accordance with the requirements of A.S.T.M. Specifications A 120 in which the weight of zinc coating is determined by a stripping test (A.S.T.M. Method A 90). However, the electrical conduit commodities described by the phrase "electrical metallic tubing and rigid conduit pipe" are usually zinc coated by electroplating and the Preece test should apply to such coatings. This change has been approved by letter ballot of the sponsoring section of Subcommittee VII which is responsible for Method A 239.

The status of all other specifications and tentative specifications under the jurisdiction of Committee A-5 remains the same as reported in 1944.

The reports of Subcommittees III and VIII are appended as part of this report. The report of Subcommittee VIII is confined largely to inspection results and findings relating to wire and wire products. For several years it has been the practice of Committee A-5 to report on wire inspections in odd-numbered years, and on hardware products in even-numbered years.

Since the last report 4 new members have been elected to Committee A-5, and 6 members have resigned; the total membership of the Committee is now 130, of whom 57 are classified as producers, 44 as consumers, and 29 as general interest members.

This report has been submitted to letter ballot of the committee which consists of 130 members; 104 members returned their ballots, of whom 98 have voted affirmatively, and 0 negatively.

Respectively submitted on behalf of the committee,

C. D. Hocker,
Chairman.

J. B. Dixon,
Secretary.

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* Presented at the Forty-Eighth Annual Meeting of the Society, June 27, 1945.

REPORT OF SUBCOMMITTEE III ON INSPECTION OF ANNAPOLIS TESTS

The specimens of copper-bearing and non-copper-bearing corrugated black sheets that have been exposed at Annapolis, Md., since October 17, 1916, were inspected on April 24 and October 12, 1944. Four failures among the No. 22 gage sheets were found at the April inspection, Z-101, 102, 108, and 501, and eight in October, B-24, I-1 and 3, K-16, Z-202, 503, 604, and 707.

One failure of No. 16 gage material was noted in October, EE-19, a wrought iron sheet with 0.35 per cent copper.

A summary of the No. 22 gage failures to date is given in the accompanying Table I.

This report of Subcommittee III has been unanimously approved by the subcommittee.

Respectfully submitted on behalf of the subcommittee,

EWART S. TAYLERSON,
Chairman.

TABLE I.—RECORD OF FAILURES AT ANNAPOLIS OF NO. 22 GAGE COPPER-BEARING AND NON-COPPER-BEARING CORRUGATED BLACK SHEETS.

Sheets Exposed October 17, 1916. Inspections Made Semiannually from 1917 to 1945.

Group	Designation	Series	Average Analysis, per cent						Number of Sheets in Test[a]	Life of Each Failed Sheet, yr.																Number of Sheets in Test	Number of Sheets Failed	Average Life of Sheets, yr.	Group
			Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper																					
Z.....	Open-hearth Steel	B	0.032	0.32	0.063	0.042	..	0.019	3	13.5	17.0	19.0	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	16.5	....Z
O.....	Open-hearth Steel	A	0.121	0.536	0.008	0.030	0.249	0.020	12	7.0	9.0	9.0	9.0	9.0	9.5	10.0	10.0	11.0	11.0	13.0	17.0	..	..	..	..	12	12	10.4	....O
B....	Open-hearth Steel	A	0.09	0.38	0.017	0.062	0.036	0.084	3	20.0	20.5	24.0	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	21.5	....B
M....	Open-hearth Steel	B	0.093	0.419	0.013	0.041	0.011	0.185	13	20.0	20.5	23.5	23.5	23.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	25.0	..	..	..	13	13	23.4	....M
B.....	Open-hearth Steel	A	0.06	0.27	0.014	0.053	0.006	0.187	9	19.5	20.0	21.5	22.0	22.5	23.0	26.0	28.0	*	..	..	..	..	..	..	..	9	8	..	....B
Z.....	Open-hearth Steel	B	0.067	0.351	0.045	0.052	0.003	0.187	3	27.0	27.5	28.0	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	27.5	....Z
T.....	Open-hearth Steel	B	0.083	0.313	0.009	0.020	0.005	0.227	14	19.5	19.5	19.5	21.5	21.5	21.5	23.0	23.5	23.5	23.5	24.0	24.0	24.0	24.0	..	..	14	14	22.3	....T
K.....	Open-hearth Steel (Acid)	A	0.107	0.447	0.091	0.046	0.004	0.237	14	24.5	28.0	*	*	*	*	*	*	*	*	*	*	*	*	..	..	14	2	..	....K
H.....	Open-hearth Steel	A	0.069	0.387	0.016	0.027	0.004	0.244	10	19.5	21.0	21.5	23.0	23.5	23.5	23.5	24.0	24.0	25.0	..	..	..	..	..	..	10	10	22.9	....H
Z.....	Open-hearth Steel	B	0.065	0.35	0.050	0.059	0.003	0.264	2	24.5	28.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	2	26.3	....Z
Z.....	Open-hearth Steel	B	0.073	0.42	0.052	0.054	Trace	0.641	3	28.0	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	1	..	....Z
S......	Open-hearth Iron	B	0.02	0.023	0.006	0.022	0.004	0.022	14	7.0	8.0	8.5	9.0	9.5	10.0	11.0	11.5	11.5	12.5	12.5	12.5	12.5	12.5	..	..	14	14	10.6	.....S
D.....	Open-hearth Iron	A	0.02	0.026	0.004	0.022	0.002	0.024	6	16.0	16.0	16.0	19.5	19.5	23.5	..	..	..	..	..	..	..	..	..	..	6	6	18.4	....D
X.....	Open-hearth Iron	B	0.021	0.055	0.007	0.031	0.004	0.027	14	10.5	13.0	13.5	14.5	14.5	16.0	16.0	16.5	16.5	17.0	17.5	17.5	18.0	19.0	..	..	14	14	15.7	X
C.....	Open-hearth Iron	A	0.01	0.028	0.002	0.027	0.002	0.141	3	17.5	20.5	23.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	20.5	C
C.....	Open-hearth Iron	A	0.015	0.028	0.006	0.036	0.003	0.194	9	16.5	16.5	18.5	19.0	19.0	20.0	20.5	21.5	21.5	..	..	..	..	..	..	..	9	9	19.2	C
U.....	Open-hearth Iron	B	0.017	0.074	0.008	0.037	0.005	0.260	13	15.5	16.5	19.0	19.0	19.0	19.0	19.0	19.5	20.0	20.0	21.0	21.0	22.5	..	..	..	13	13	19.3	....U
V.....	Open-hearth Iron	B	0.018	0.051	0.007	0.021	0.005	0.304	14	17.0	17.0	17.5	18.5	18.5	19.0	20.0	20.0	20.5	21.0	22.0	22.0	22.5	24.0	..	..	14	14	20.0	V
A.....	Bessemer Steel	A	0.038	0.386	0.089	0.040	0.007	0.014	15	15.5	16.5	16.5	17.0	17.0	17.0	18.0	19.0	19.0	19.5	19.5	19.5	19.5	19.5	20.0	..	15	15	18.2	....A
Z......	Bessemer Steel	B	0.063	0.41	0.102	0.044	0.009	0.013	3	11.5	11.5	11.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	11.5	....Z
Z.....	Bessemer Steel	B	0.077	0.44	0.095	0.036	0.003	0.140	3	27.5	27.5	27.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	27.5	....Z
I......	Bessemer Steel	A	0.041	0.365	0.097	0.068	0.008	0.252	15	24.0	26.0	26.5	26.5	26.5	26.5	27.0	28.0	28.0	*	*	*	*	*	*	..	15	9	..	I
Z.....	Bessemer Steel	B	0.058	0.37	0.093	0.043	0.009	0.269	3	28.0	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	1	..	....Z
Z.....	Bessemer Steel	B	0.055	0.38	0.110	0.046	..	0.527	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	..	....Z
Y.....	Wrought Iron	B	0.03	0.055	0.139	0.021	0.218	0.020	3	18.0	19.5	23.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	20.3	....Y
E.....	Wrought Iron	A	0.033	0.034	0.114	0.021	0.134	0.283	10	19.5	20.5	21.0	21.0	23.0	23.0	23.0	23.0	24.0	25.0	..	..	..	..	..	..	10	10	22.3	....E
							Total......		214																Total...	214	188		

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* Indicates unfailed sheet.

[a] The number of sheets in the test indicated in this table is less than the number shown in earlier reports because certain sheets were discarded due to mechanical damage.

REPORT OF SUBCOMMITTEE VIII ON FIELD TESTS OF METALLIC COATINGS

Subcommittee VIII on Field Tests of Metallic Coatings has carried on the regular inspection of its large collection of galvanized sheet specimens, metallic-coated hardware parts, and wire and wire products which are undergoing atmospheric exposure tests.

EXPOSURE TESTS ON WIRE AND WIRE PRODUCTS

The report of the Wire Inspection Committee, comprising the bulk of the report of Subcommittee VIII, is appended.

GALVANIZED SHEET EXPOSURE TESTS

The inspection of the sheets located at Brunot Island (Pittsburgh); Altoona; State College, Pa.; and Sandy Hook, N. J., has been continued on the routine spring and fall schedule. The annual Key West, Fla., inspection scheduled for this spring was canceled because of the present national emergency. The new failures observed during 1944 follow:

Brunot Island, Pa.—On April 28, two sheets (NHK-B and SHV-B) in the 0.75-oz. (No. 22-gage) coating class were perforated. On October 9, one sheet (RBH-B) in the 2.0-oz. coating class, three sheets (WCM-T, VCH-T, and VCH-B) in the 1.5-oz. coating class and one sheet (VEA-B) in the 1.25-oz. coating class were perforated. Two sheets (SAM-B and CAV-B) in the 2.5-oz. coating class were 100 per cent rusted.

Altoona, Pa.—On May 10, no new failures were reported. On October 9, one sheet (RBE-T) in the 2.0-oz. coating class and one sheet (TCL-T) in the 1.5-oz. coating class were perforated.

State College, Pa.—On April 22, no new failures were reported. On October 10, one sheet (VBC-T) in the 2.0-oz. coating class and two sheets (YCA-B and CCC-B) in the 1.5-oz. coating class were reported rusted for the first time.

Sandy Hook, N. J.—On April 26, three sheets (RCL-T, TCT-T, and YCL-B) in the 1.5-oz. coating class were 100 per cent rusted. On October 11, one sheet (CAM-B) in the 2.5-oz. coating class was reported rusted for the first time and one sheet (NCL-T) in the 1.5-oz. coating class was 100 per cent rusted.

Key West, Fla.—All new observations in 1944 were given in the 1944 report of Subcommittee VIII.[1]

A complete summary of the sheet data will be given in next year's report.

EXPOSURE TESTS OF METALLIC-COATED HARDWARE

The hardware exposures at State College, Pa., and Sandy Hook, N. J., were inspected on a schedule coinciding with that of the Sheet Inspection Group. The only other exposure remaining is at Key West, Fla., which was not inspected in 1945. Following past practice, the hardware data are scheduled for inclusion in complete form in next year's report.

This report has been submitted to letter ballot of the subcommittee which consists of 62 members; 42 members returned their ballots, of whom 40 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the subcommittee.

C. E. Reinhard,
Chairman.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 92 (1944).

REPORT OF WIRE INSPECTION COMMITTEE ON FIELD TESTS OF WIRE AND WIRE PRODUCTS

(COVERS 1943 AND 1944 INSPECTIONS)

NOTE.—Reference to the previously published reports of Subcommittee VIII on Field Tests of Metallic Coatings, of Committee A-5 on Corrosion of Iron and Steel, which appeared in the 1939, 1941, and 1943 *Proceedings*[1] will be helpful in certain studies of these exposure test results. These earlier reports contain descriptions of the test methods and micrographs and other characterizations of specimens in the test as well as the data assembled in inspections prior to 1943.

This report presents the results of the atmospheric corrosion tests on wire and wire product specimens after exposure for about eight years at each of eleven locations. These eleven test sites have atmospheres of divers types, including severely industrial, mildly industrial, seacoast, and rural. At each location, more than 900 specimens were exposed. These included short lengths of wire (42 in. long) and wire strand at all locations; farm field fence at nine sites; barbed wire at eight locations; and chain link fence at eight locations. Previous reports show the details of the number and nature of the test specimens involved at each location.[2]

The extent of corrosion on specimens is being measured by the following:

1. Visual examination of all specimens at the test locations. At the time of inspection, records are made of the appearance of each specimen. Prior to the time of rusting the specimens are noted as appearing "metallic," "gray," etc. After rusting has begun, estimates are made of the percentage of area rusted on each specimen.

2. Tension tests on the unfabricated wire specimens. These are the specimens exposed in groups of seven comparison samples taken from the same lot of wire and supposedly alike. An attempt is made to remove and test the first specimen of each heptad when it has lost 5 to 10 per cent of its strength, and the seventh specimen when it has lost some 75 per cent of its strength.

3. Loss of weight tests on lengths of zinc-coated wire (each about 42 in. long) weighed and measured before exposure. The working scheme for handling these specimens at each location is to remove one fourth at a time—the first quarter when they have lost a relatively small percentage of their coating, the last quarter when most of the coating has gone but before significant rusting has occurred.

Semi-annual inspections have been made at Pittsburgh, Bridgeport, Sandy Hook, and State College by a traveling committee and annual inspections have been made at the other test sites by the university people in charge of the test plots. These people are:

L. W. Neubauer	Davis and Santa Cruz, Calif.
H. P. Smith	College Station, Tex.
Henry Giese	Ames, Iowa
F. C. Fenton	Manhattan, Kans.
I. D. Mayer	Lafayette, Ind.
B. A. Jennings	Ithaca, N. Y.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 99 (1939); Vol. 41, p. 101 (1941); and Vol. 43, p. 73 (1943).

[2] *Ibid.*, Vol. 39, p. 157 (1939).

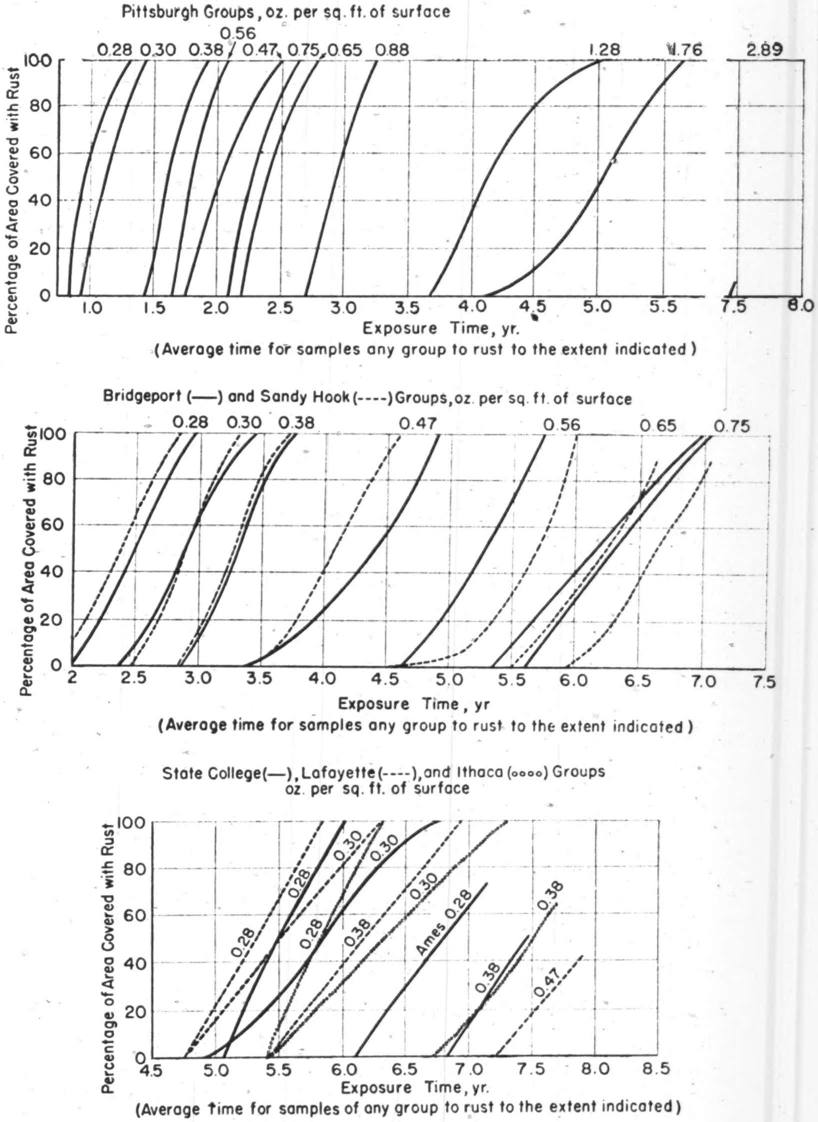

FIG. 1.—Progressive Development of Rust on Zinc Coated Unfabricated Wire (Coating Weight Groups in which all of the Samples Are Rusted).

Findings from Visual Examination for Corrosion at the Test Plots:

Summaries of the records of inspections through 1944 are shown in the following condensed tabulations and figure:

Table A shows the corrosion condition of the zinc-coated unfabricated wire specimens after exposure for about eight years at each of eleven sites.

Figure 1 shows the progressive development of rust on zinc-coated unfabricated wire specimens for all groups which have become 100 per cent rusted

TABLE A.—CORROSION CONDITIONS OF ZINC-COATED UNFABRICATED WIRES AFTER APPROXIMATELY EIGHT YEARS' EXPOSURE.

R = rust; Y = yellowed; G = gray; M = metallic; MG and GY = intermediate states; TrR = trace rust.

Location	Coating Group, oz. per sq. ft. of surface										
	0.20 to 0.30	0.25 to 0.35	0.35 to 0.45	0.45 to 0.55	0.50 to 0.60	0.60 to 0.70	0.70 to 0.85	0.80 to 1.00	1.20 to 1.35	1.60 to 1.85	2.00 or more
Pittsburgh, Pa.	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	44R
Sandy Hook, N. J.	100R	100R	100R	100R	100R	87R	99R	53R	GY	TrR	G
Bridgeport, Conn.	100R	100R	100R	100R	100R	99R	99R	70R	GY	TrR	G
State College, Pa.	100R	92R	77R	7R	1R	TrR	GY	GY	G	G	G
Lafayette, Ind.	100R	99R	100R	40R	20R	2R	G	G	G	MG	MG
Ames, Iowa	82R	53R	7R	G	G	G	G	G	G	G	G
Manhattan, Kans.	G	G	G	G	MG	MG	MG	MG	MG	MG	MG
Ithaca, N. Y.	100R	98R	72R	5R	TrR	TrR	MG	MG	G	M	M
Santa Cruz, Calif.	G	TrR	G	G	MG	MG	MG	MG	..	MG	MG
College Station, Tex.	5R	5R	GY	GY	GY	G	GY	G	G	G	G
Davis, Calif.	G	G	G	G	G	G	MG	MG	..	MG	MG

TABLE B.—CORROSION CONDITIONS OF UNFABRICATED WIRES CARRYING COATINGS OTHER THAN ZINC—AFTER APPROXIMATELY EIGHT YEARS' EXPOSURE.

D = dark to exclusion of better observation; Y = yellowed; G = gray; M = metallic; MG and GY = intermediate states; SR and SY = superficial R and Y; R + Y = indistinguishable proportions of R and Y; Gn = green; Br = brown; PHR and PHY = rust or yellowed in pin holes.

Location	Coating Groups and Corrosion Resistant Groups				
	Copper Covered Wires[a]	Lead Coated Wires[b]	12 to 14% Cr Cold Drawn	12 to 14% Cr Air Quenched	18% Cr, 8% Ni
Pittsburgh, Pa.	D	D25R	D	D	D
Sandy Hook, N. J.	Gn	40R+Y	Y	Y	G
Bridgeport, Conn.	Gn	2R+Y	G	G	MG
State College, Pa.	Gn	45R+Y	M	M	M
Lafayette, Ind.	Gn	60R+Y	M	M	M
Ames, Iowa	Br	30R+Y	SY	SY	MY
Manhattan, Kans.	Br	15PHR	MG	MG	M
Ithaca, N. Y.	Br	3R	MG	M	M
Santa Cruz, Calif.	Br	20SR	55SR	25SR	MG
College Station, Tex.	Br	40R+Y	95R+Y	85R+Y	MY
Davis, Calif.	Br	25SR	45SR	20SR	MG

[a] Weight of coating 7 to 9 oz. per sq. ft. of surface.
[b] Weight of coating 1.4 to 1.9 oz. per sq. ft. of surface.

TABLE C.—CORROSION CONDITIONS OF FARM FIELD FENCE AFTER APPROXIMATELY EIGHT YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY = intermediate stage; TrR = trace rust; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown.

Location	Coating Group, oz. zinc per sq. ft. of surface							Copper Covered[a]	Lead Coated[b]	Cr-Ni Steel
	0.20 to 0.30	0.25 to 0.35	0.35 to 0.45	0.45 to 0.55	0.50 to 0.60	0.60 to 0.70	0.70 or more			
State College, Pa.	55R	45R	5R	TrR	GY	GY	G	Gn	30R+Y	MG
Lafayette, Ind.	98R	85R	70R	30R	10R	3R	MG	Gn	15PHR	M
Ames, Iowa	30R	20R	TrR	TrR	GY	GY	G	Br	50PHY	SY
Manhattan, Kan.	TrR	TrR	TrR	TrR	G	MG	MG	Br	15PHR	MG
Ithaca, N. Y.	75R	75R	60R	10R	1R	TrR	M	Br	5R	MG
Santa Cruz, Calif.	GY	GY	G	GY	GY	GY	MG	Br	35SR	30SR
College Station, Tex.	10R	3R	4R	3R	2R	2R	G	Br	20SR	30SR
Davis, Calif.	G	G	G	G	G	MG	MG	Br	45SR	50SR

[a] Weight of coating 7.42 oz. per sq. ft. of surface.
[b] Weight of coating 1.48 oz. per sq. ft. of surface.

and for all groups of wire, which, while not 100 per cent rusted, show some rust on each specimen in the group.

Table B shows the corrosion condition of unfabricated wire of copper-covered steel, lead-coated steel and corrosion-resistant steel exposed at each of eleven test sites.

TABLE D.—CORROSION CONDITIONS OF BARBED WIRE AFTER APPROXIMATELY EIGHT YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY = intermediate stage; TrR = trace rust; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown.

Location	Coating Group, oz. zinc per sq. ft. of surface							Copper Covered[a]	Lead Coated[b]
	0.20 to 0.30	0.35 to 0.45	0.50 to 0.60	0.70 to 0.85	0.80 to 1.00	1.60 to 1.80	2.00 or more		
State College, Pa.	100R	55R	Y	G	G	G	G	Gn	....
Lafayette, Ind.	100R	93R	8R	MG	MG	MG	MG	Gn	15PHR
Ames, Iowa	50R	3R	G	G	G	G	G	Br	15PHY
Manhattan, Kans.	TrR	TrR	G	MG	MG	MG	MG	Br	5PHR
Ithaca, N. Y.	99R	55R	4R	M	MG	M	M	Br	5R
Santa Cruz, Calif.	TrR	G	G	MG	G	G	MG	Br	20SR
College Station, Tex.	3R	2R	1R	G	G	G	G	Br	60R+Y
Davis, Calif.	TrR	G	G	MG	MG	MG	MG	Br	30SR

[a] Weight of coating 3.97 oz. per sq. ft of surface.

[b] Weight of coating 1.83 oz. per sq. ft. of surface.

TABLE E.—CORROSION CONDITIONS OF CHAIN LINK FENCE AFTER APPROXIMATELY EIGHT YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY = intermediate stage; TrR = trace rust; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown; D = dark, to the exclusion of a better observation.

Location	Coating Group, oz. zinc per sq. ft. of surface					Copper Covered[c]	Lead Coated[d]	Corrosion Resistant
	0.29 to 0.52[a]	1.13 to 1.22[a]	2.09 to 2.92[a]	1.40 to 1.97[b]	4.21 or more[b]			
Pittsburgh, Pa.	100R	100R	65R	100R	25R	..	20R	D
Sandy Hook, N. J.	100R	Y	G	3R	G	Gn	60R+Y	M
Bridgeport, Conn.	100R	GY	G	TrR	G	Gn	10R+Y	MG
State College, Pa.	40R	G	G	G	G	Gn	70R+Y	M
Lafayette, Ind.	80R	G	MG	MG	MG	Gn	10PHR	M
Ithaca, N. Y.	70R	MG	M	MG	MG	Br	2R	M
Santa Cruz, Calif.	GY	MG	MG	MG	MG	Br	15SR	MG
Davis, Calif.	G	MG	MG	MG	MG	Br	25SR	MG

[a] Coated before weaving.

[b] Coated after weaving.

[c] Weight of coating 8.52 oz. per sq. ft. of surface.

[d] Weight of coating 1.75 oz. per sq. ft. of surface.

TABLE F.—CORROSION CONDITIONS OF WIRE STRAND AFTER APPROXIMATELY EIGHT YEARS' EXPOSURE.

R = rust; Y = yellowed; R+Y = indistinguishable proportions of R and Y; G = gray; M = metallic; MG and GY = intermediate stage; TrR = trace rust; PHR, PHY = pin hole rusting or yellowing; SR, SY = superficial rust or yellowing; Gn = green; Br = brown.

Location	Coating Group, oz. zinc per sq. ft. of surface				Lead Coated[a]
	0.69 to 0.93	1.03 to 1.17	1.32 to 1.51	1.71 to 2.47	
Pittsburgh, Pa.	100R	100R	50R	20R	25R
Sandy Hook, N. J.	G	G	G	G	90R+Y
Bridgeport, Conn.	G	G	G	G	35R+Y
State College, Pa.	G	G	G	G	70R+Y
Lafayette, Ind.	MG	MG	MG	MG	45PHR
Ames, Iowa	G	G	G	G	70PHY
Manhattan, Kans.	MG	MG	MG	MG	20R
Ithaca, N. Y.	M	MG	MG	M	35R
Santa Cruz, Calif.	G	G	MG	MG	45SR
College Station, Tex.	G	G	G	G	55R+Y
Davis, Calif.	MG	MG	MG	MG	45SR2R

[a] Weight of coating 1.96 oz. per sq. ft. of surface.

Table C shows the corrosion condition of farm field fence exposed at all locations except Pittsburgh, Sandy Hook and Bridgeport. There are many instances where the corrosion state of the top of the fence is more advanced than that of the bottom of the fence; also, different states of corrosion exist between line and stay wires. These differences are not shown in the summary table, but are shown in the detailed Table III. The corrosion performance of any individual specimen of barbed wire or of farm field fence listed in Tables II and III may be directly compared with the performance of specific unfabricated wire specimens. The Reference Information Table (Plate III)[2a] in this respect shows the lot numbers of wires used in fabricating all fence and barbed wire samples.

Table D shows the corrosion condition of barbed wire exposed at all locations except Pittsburgh, Sandy Hook, and Bridgeport.

Table E shows the corrosion condition of chain link fence exposed at all locations except Ames, Manhattan, and College Station.

Table F shows the corrosion condition of wire strand exposed at each of eleven test sites.

The detailed corrosion inspection records collected in 1943 and 1944 are presented at the end of this report in Table I (Plate I)[2a] for unfabricated wire specimens, Table II for barbed wire, Table III for farm field fence, Table IV for chain link fence, and Table V for wire strand.

These tables are similar in form to the tables in previous reports except that in the case of Table I (Plate I) for unfabricated wire specimens all the inspection data from Sandy Hook and Bridgeport have been assembled in a separate table (Table IA) (Plate II),[2a] together with a graphic presentation of the period of rusting, for all groups of zinc-coated wires which have shown appreciable rusting.

Findings from Weight Loss Specimens:

At the start of the test 144 wires (16 alike of each of 9 wire lots) were exposed at Pittsburgh, at Sandy Hook, and at State College. The test procedure plan was to remove the specimens one fourth at a time from each location, taking the last quarter when the coating was nearly gone but before rusting started. All of the removals have been made from Pittsburgh and Sandy Hook and three fourths of the specimens have been removed from State College. The earlier removals from Pittsburgh, State College and Sandy Hook were reported in the 1939, 1941, and 1943 *Proceedings*.[3] Table VII shows the results obtained from the third removals from State College which were the only weight loss data assembled since the last published report. These data are in line with previously reported findings that:

1. There is a tendency for the light gages of wire to lose coating somewhat faster than the heavier gages.

2. There is an indication that there is a very slight decrease in the rate of coating loss with increasing periods of exposure.

3. The over-all average annual loss of coating in ounces per square foot of surface at Pittsburgh is 0.369; at Sandy Hook it is 0.117; and at State College it is 0.063.

4. There is not a consistent indication that any one of the three groups (A or B or C) loses coating at a more rapid rate than the other two, although the data might be interpreted to indicate

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[2a] This plate appears in envelope on inside back cover.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 156 (1939); Vol. 41, p. 101 (1941); and Vol. 43, p. 78 (1943).

that group C loses weight at the lowest rate.

5. The time required for first rust to appear on samples thus far rusted at Pittsburgh and at Sandy Hook checks reasonably well with the time that would be expected from the data on the weight loss specimens.

Findings from Specimens Removed for Tension Tests:

There were originally about 840 tensile strength specimens exposed at each site. In the 1939, 1941, and 1943 *Proceedings*[3] the results of tensile strength and elongation tests on 1017 wires were reported. Since then 275 additional wires have been removed, divided among the different test sites as shown in Table G. The detailed results of the tests on these 275 wires are shown in Table VI.

TABLE G.—NUMBER OF TENSILE STRENGTH SPECIMENS REMOVED FOR TEST.

Exposure Site	Number of Wires Removed in 1943 and 1944				Wires Removed Prior to 1943	Total Removed to Date
	Bare Steel	Zinc Coated	Lead Coated	Other Types		
Pittsburgh, Pa.	4	133	4	0	405	546
Sandy Hook, N. J.	11	48	0	0	148	207
Bridgeport, Conn.	0	35	4	0	130	169
State College Pa.	12	20	4	0	52	88
All other sites	0	0	0	0	282	282
	27	236	12	0	1017	1292

Pittsburgh is the most corrosive of the test sites and consequently more specimens have been removed from there than from any other location. Of the 840 specimens originally at Pittsburgh, 545 (65 per cent) have been removed.

The corrosion-resistant steel wires (high chromium and nickel chromium content wires) and copper covered steel wires (coating weights 7 to 9 oz. per sq. ft. of surface) that were removed from Pittsburgh after an exposure of about five years showed no loss in strength.

Lead-coated wires were removed for tensile strength tests in 1943 from State College, Bridgeport, and Pittsburgh after an exposure of about 6½ yr. These wires have a coating of 1.4 to 1.9 oz. per sq. ft. of surface. (See 1944 report for a description of the particular type of coating on these lead-coated wires.) None of these wires showed any significant loss of strength although the specimens at that time showed considerable pinhole rusting. Apparently the pinhole rusting observed on these specimens, while undesirable from an appearance standpoint, does not materially affect the strength of the specimen. There are various instances where the lead-coated wires appear less corroded now

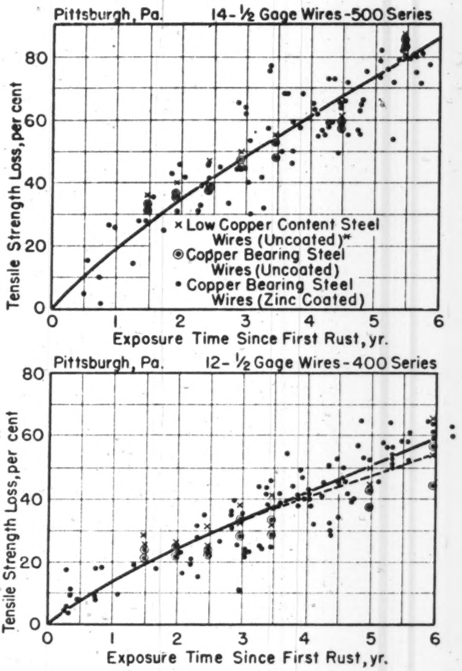

FIG. 2.—Tensile Strength Loss for Periods of Exposure Since First Rust.

* Low copper content wires have 0.05 to 0.08 per cent copper, all other wires have about 0.25 per cent copper.

than they did at earlier inspections, but at some locations, Pittsburgh for example, progressive overall corrosion is apparent.

TABLE H.—LOSS OF TENSILE STRENGTH SHOWN BY STEEL WIRES AFTER VARIOUS PERIODS OF EXPOSURE, PITTSBURGH, PA.

500 SERIES (14½ GAGE) AND 400 SERIES (12½ GAGE) UNFABRICATED WIRES.

Wire Lot	Exposure Until First Rust, yr.	First Test			Second Test			Third Test			Fourth Test			Fifth Test			Sixth Test			Seventh Test		
		Exposure Since 1R, yr.	Tensile Str. Loss		Exposure Since 1R, yr.	Tensile Str. Loss		Exposure Since 1R, yr.	Tensile Str. Loss		Exposure Since 1R, yr.	Tensile Str. Loss		Exposure Since 1R, yr.	Tensile Str. Loss		Exposure Since 1R, yr.	Tensile Str. Loss		Exposure Since 1R, yr.	Tensile Str. Loss	
			per cent	per cent per year		per cent	per cent per year		per cent	per cent per year		per cent	per cent per year		per cent	per cent per year		per cent	per cent per year		per cent	per cent per year
No. 501[a]	0	1.48	36.0	24	1.94	39.9	20	2.45	46.0	19	2.93	49.0	17	3.48	55.0	16	4.50	61.0	13	5.48	87.0	16
No. 506	0	1.48	32.7	22	1.94	35.5	18	2.45	37.5	15	2.93	45.2	15	3.48	48.1	14	4.50	57.8	13	5.48	82.7	15
No. 507	0	1.48	31.1	21	1.94	36.1	18	2.45	37.8	15	2.93	47.1	16	3.48	52.9	15	4.50	59.6	13	5.48	84.9	15
No. 510	1.20	0.28	0	0	0.74	10.0	13	1.25	14.0	11	1.73	25.0	15	2.28	31.0	14	3.72	46.0	12	4.75	65.0	14
No. 511	0.60	0.88	26.3	30	1.34	28.1	21	1.85	42.5	23	2.33	38.6	17	2.88	43.8	15	4.32	59.6	14	5.35	79.0	14
No. 512	0.50	0.98	26.1	27	1.44	27.7	19	1.95	30.8	16	2.43	41.5	17	2.98	44.6	15	4.42	49.2	11	5.45	83.0	15
No. 520	1.20	0.28	0	0	0.74	1.8	2	3.30	32.1	10	4.28	58.9	14	4.75	55.4	12	4.75	55.4	12	5.75	71.5	12
No. 521	1.75	0	−3.7	0	0.20	−5.5	0	2.75	33.3	12	3.73	59.3	16	4.20	55.6	13	4.20	55.6	13	5.20	75.9	14
No. 522	1.45	0	−2.0	0	0.50	5.0	10	3.05	40.0	13	4.03	65.0	16	4.50	64.0	14	4.50	64.0	14	5.50	79.7	14
No. 530	1.20	0.28	−1.3	0	0.74	−4.5	0	3.72	50.0	13	4.28	72.6	17	4.75	62.9	13	5.30	53.3	10	5.75	80.7	14
No. 531	1.40	0.08	8.0	0	0.54	15.0	28	3.52	50.0	14	4.08	63.0	15	4.55	66.0	15	5.10	82.0	16	5.55	79.8	14
No. 540	1.85	0.10	−6.8	0	3.07	53.4	18	3.63	68.3	19	4.10	61.7	15	4.60	71.7	16	5.10	78.3	15	5.65	80.0	14
No. 541	2.60	0	−1.5	0	2.32	32.9	14	2.88	65.7	23	3.35	57.2	17	3.90	68.5	17	4.35	72.9	17	4.90	75.7	15
No. 542	1.65	0.30	0	0	3.27	41.2	13	3.83	57.8	15	4.30	59.8	14	4.80	65.7	14	5.30	71.6	14	5.85	77.4	13
No. 543	1.85	0.10	−1.7	0	3.07	35.0	12	3.63	68.3	19	4.10	55.0	13	4.60	55.0	12	5.10	73.3	14	5.65	75.0	13
No. 551	4.50	0.42	4.6	11	2.00	46.3	23	2.45	47.2	19	3.00	63.8	21	3.40	77.8	23	3.40	77.8	23	...	...	..
No. 552	4.90	0	−1.0	0	1.60	35.5	21	2.05	42.0	20	2.60	45.1	17	3.00	64.5	21	...	...	...	...	...	..
No. 400[a]	0	1.48	25.0	17	1.94	23.0	12	2.45	25.0	10	2.93	32.3	11	3.48	32.3	9	4.92	43.8	9	5.95	54.2	9
No. 401[a]	0	1.48	28.9	20	1.94	25.5	13	2.45	31.1	13	2.93	38.0	13	3.48	41.2	12	4.92	50.0	10	5.95	65.6	10
No. 405	0	1.48	23.6	16	1.94	23.7	12	2.45	23.7	10	2.93	33.0	11	3.48	33.0	10	4.92	43.5	9	5.95	56.8	9
No. 406	0	1.48	21.3	14	1.94	21.3	11	2.45	22.3	9	2.92	27.7	9	3.48	28.7	8	4.92	37.2	7	5.95	44.7	7
No. 410	0.65	0.83	18.0	22	1.29	18.8	15	2.28	28.1	12	2.83	30.7	11	4.27	45.7	11	4.83	64.9	13	5.30	51.7	10
No. 411	0.85	0.63	7.3	12	1.09	9.7	9	2.08	16.3	8	2.63	26.8	10	4.07	31.8	8	4.63	41.5	9	5.10	45.5	9
No. 412	1.25	0.23	4.8	21	0.69	8.5	12	1.68	17.5	10	2.23	19.3	9	3.67	54.2	15	4.23	...	...	4.70	40.4	9
No. 421	1.60	0	4.3	0	0.34	3.2	10	2.90	25.5	9	3.88	40.4	10	4.35	28.6	7	5.35	49.8	9	5.35	55.2	10
No. 422	1.45	0	8.0	0	0.50	5.0	10	3.05	23.0	8	4.03	40.0	10	4.50	34.0	8	...	...	..	...	...	..
No. 423	1.25	0.23	17.5	...	0.70	17.5	25	3.25	25.0	8	4.23	41.2	10	4.70	40.0	9	...	...	..	...	...	..
No. 430	2.60	0	−1.3	0	0	−4.5	0	2.32	15.4	7	2.88	35.3	12	3.35	38.5	11	4.35	50.0	12	5.30	56.5	11
No. 431	1.60	0	6.8	0	0.34	11.4	33	3.32	23.9	7	3.88	41.5	11	4.35	39.8	9	5.35	53.4	10	6.30	59.1	9
No. 432	1.60	0	−2.0	0	0.34	9.8	29	3.32	0	...	3.88	38.2	10	4.35	42.2	10	5.35	52.0	10	6.30	62.7	10
No. 440	2.60	0	−6.8	0	2.32	31.4	14	2.88	39.8	14	3.35	41.6	12	3.90	48.3	12	4.90	52.5	11	5.30	63.5	12
No. 441	1.90	0.55	−5.8	0	3.02	23.1	8	3.58	41.3	12	4.05	42.4	10	4.60	49.1	11	5.60	60.5	11	6.00	63.5	11
No. 442	2.00	0.45	7.5	17	2.92	10.6	3	3.48	45.7	13	3.95	46.8	12	4.50	52.2	12	5.50	57.4	10	5.90	63.9	11
No. 443	1.90	0.55	−1.3	0	3.02	22.0	7	3.58	38.0	11	4.05	41.4	10	4.60	46.0	10	5.60	58.0	10	6.00	60.6	10
No. 444	2.70	0	0	0	2.22	21.1	10	2.78	37.7	14	3.25	43.8	13	3.80	43.0	11	4.80	56.1	12	5.20	57.0	11
No. 495	1.90	0.55	−0.7	0	3.02	23.4	8	3.58	38.0	11	4.05	38.0	9	4.60	44.7	10	5.60	52.0	9	6.00	57.7	10
No. 450	2.95	2.53	22.6	...	3.50	24.4	7	4.00	40.9	10	4.55	44.7	10	5.00	51.8	10	...	...	..	...	...	..
No. 451	4.50	0.98	21.6	...	2.00	23.6	12	2.45	34.3	14	3.00	34.3	11	3.40	43.1	13	...	...	..	...	...	..

[a] Low copper content wires, 0.05 to 0.08 per cent copper. All other wires have about 0.25 per cent copper.

In the 1943 *Proceedings*[4] there were shown the results of all tensile strength tests on uncoated and zinc-coated mild steel wires removed from the Pittsburgh site. During 1943 and 1944 practically all the remaining No. 14½-gage and No. 12½-gage specimens were removed and tested, and the data from these tests together with the earlier data on these

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[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 83 (1943).

TABLE II.—REPORT OF INSPECTIONS OF BARBED WIRE SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pinholes; B, Br, Gn, respectively, signify corroded to a black, brown or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; MG = intermediate M and G; GY predominately gray but showing indication of Y; RB = rust on barbs; SR = superficial rust; asterisk (*) = speckled; R+Y = indistinguishable proportions of R and Y.

Coating Group	Average Coating, oz. per sq. ft. of surface[a]	Wire[b]	State College, Pa.				Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			5.42 yr.	5.88 yr.	6.42 yr.	6.87 yr.	7.03 yr.	8.00 yr.	6.93 yr.	7.90 yr.	6.92 yr.	7.89 yr.	6.95 yr.	7.94 yr.	6.90 yr.	7.85 yr.	6.87 yr.	7.80 yr.	6.91 yr.	7.85 yr.
0.20 to 0.30	0.30	No. C410....	100R	100R		100R	100R	100R	75R	100R	GY	TrR	100R	100R	G	G	5R	5R	G	G
	0.24	No. C411....	40R	100R		100R	100R	100R	40R	40R	GRB	GRB	80R	100R	GRB	GRB	GYRB	2R	GRB	GRB
	0.29	No. C412....	YRB	40R		100R	90R	100R	GRB	GRB	G	G	55R	95R	G	G	GY	1R	G	G
0.35 to 0.45	0.37	No. C421....	Y	10R		35R	85R	90R	G	G	G	G	10R	40R	G	G	GY	1R	G	G
	0.47	No. C422....	YRB	10R		35R	80R	90R	G	G	G	TrR	10R	20R	G	G	1R	5R	G	G
	0.31	No. C420....	10R	60R		90R	100R	100R	G	10R	G	G	75R	100R	G	G	GY	1R	G	G
0.50 to 0.60	0.48	No. C430....	Y	Y		YRB	GRB	12R	G	G	G	G	G	1RRB	G	G	GY	2R	G	G
	0.54	No. C431....	YRB	5R		YRB	10R	12R	G	G	G	G	15R	10R	G	G	GY	2R	G	G
	0.57	No. C432....	G	G		G	MG	MGRB	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
0.70 to 0.85	0.72	No. C441....	G	G		G	MG	MG	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
	0.78	No. C442....	G	G		G	MG	MG	G	G	MG	MG	MG	M	G	G	G	G	G	MG
	0.74	No. C443....	G	G		G	G	G	G	G	MG	MG	MG	G	MG	MG	G	G	MG	MG
0.80 to 100	0.97	No. C445....	G	G		G	G	MG	G	G	MG	MG	G	MG	G	G	G	G	MG	MG
	0.92	No. C446....	G	G		G	G	G	G	G	MG	MG	MG	MG	G	G	G	G	MG	MG
1.60 to 1.80	1.64	No. C450....	G	G		G	G	G	G	G	MG	MG	MG	MG	G	G	G	G	MG	MG
	1.50	No. C452....	G	G		G	MG	MG	G	G	MG	MG	M	M	G	G	G	G	G	G
	1.83	No. C451....	G	G		G	MG	MG	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
Heavy Coating	1.99	No. C494....	G	G		G	MG	MG	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
	1.99	No. C494....	G	G		G	MG	MG	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
	2.00	No. C447....	G	G		G	MG	MG	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
Copper covered (3.97 oz. per sq. ft.)......		No. C025....	Gn	GnRB		GnRB	Gn	Gn	....	Br	Br	Br	Br	Br	BrRB	BrRB	Br	Br	BrRB	BrRB
		No. C025....	Gn	GnRB		GnRB	....	....	Br	....	....	....	Br	....	....	....	....	....	....	....
Lead coated (1.83 oz. per sq. ft.)..........		No. C045....	....	....	....	....	10PHR	15PHR	15PHY	15PHY	15PHY	5PHR	5R	5R		....	15R+Y	55R+Y	25SR	30SR
		No. C045....		....	....	....	10PHR	15PHR	15PHY	15PHY	....	....	....	....	20SR	20SR	15R+Y	65R+Y	....	....

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

[b] These barbed wire numbers do not always correspond to the unfabricated wire numbers as seen below:

Barbed Wire	Unfabricated Wire	Barbed Wire	Unfabricated Wire
No. C410	No. 410	No. C441	No. 442
No. C411	....	No. C442	No. 441
No. C412	No. 412	No. C443	No. 443
No. C421	....	No. C445	....
No. C422	No. 421	No. C446	....
No. C420	No. 423	No. C447	....
No. C430	No. 431	No. C450	....
No. C431	No. 430	No. C452	No. 450
No. C432	No. 432	No. C451	No. 451
		No. C494	....

TABLE III.—REPORT OF INSPECTIONS

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or holes; B, Br, Gn, respectively signify corroded to a black, brown, or green appearance; D = dark (dirt or soot) to the exclusion or SR = superficial Y and superficial R, respectively; Asterisk (*) = speckled appearance. Figures (as 5, 20, 50, 100) are per-stay wires. Where two values are shown separated by & (90R&Y) the first applies to the top wires of the fence and the second to

Coating Group	Average Coating, oz. per sq. ft. of surface[a]	Fence	State College, Pa.				Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.	
			5.42 yr.	5.88 yr.	6.42 yr.	6.87 yr.	7.03 yr.	8.00 yr.	6.93 yr.	7.90 yr.	6.92 yr.	7.89 yr.
0.20 to 0.30 Avg. 0.28	0.27	No. 512...	50R&Y	80R	90R&GY	90R-100R	100R	100R	100R&G	100R&G	GY	TrR
	0.30	No. 410...	50R&GY	25R&GY	60R&GY	10R-70R	90R&100R	95R	100R&G	100R&G	GY	TrR
	0.28	No. 411...	Y	5R	10R&GY	5R	80R&G	100R	GY	G-TrR	G	G
	0.29	No. 510...	Y-5R	25R	20R&GY	90R	90R&G	100R	GY	GY-TrR	GY	G
	0.29	No. 412...	Y	Y-20R	40R&GY	50R-95R	90R&10R	90R	GY	TrR&G	G	G
	0.24	No. 511...	30R&G	75R	60R&GY	90R-100R	90R&G	100R	G-50R	G-50R	G	G
0.25 to 0.35 Avg. 0.30	0.25	No. 315...	40R-60R	80R	90R&Y	99R	90R&50R	90R	50R&G	70R&G	G	TrR
	0.28	No. 215...	90R&G	60R&Y	50R	70R	100R	90R	100R&G	100R&G	GY	TrR
	0.38	No. 317...	Y	Y	Y	5R	35R	75R	GY	GY	G	G
	0.32	No. 316...	Y	2R	10R&Y	20R	75R&G	80R	GY	5R&GY	G	G
	0.30	No. 216...	Y	1R	Y	30R	60R	80R&G	GY	8R&G	G	G
0.35 to 0.45 Avg. 0.38	0.36	No. 520...	Y	Y	GY	5R-20R	80R&G	90R&50R	GY	GY	G	G
	0.35	No. 422...	Y	5R&Y	2R	10R-25R	80R&G	80R	GY	GTrR	GY	TrR
	0.31	No. 423...	Y	Y	G	5R-20R	75R	90R	GY	GY	G	G
	0.44	No. 522...	Y	Y	G	Y	50R&G	60R&G	G	G	G	G
	0.38	No. 521...	Y-5R	10R	10R&GY	TrR-90R	70R&G	75R&G	G	GTrR	G	G
	0.47	No. 421...	Y-5R	5R&Y	10R&Y	Y-10R	15R	20R	GY	GTrR	G	G
0.45 to 0.55 Avg. 0.46	0.44	No. 325...	Y	Y	Y	Y	10R	30R	GY	GY	G	G
	0.50	No. 228...	Y	Y	Y	Y	10R	30R	GY	G	G	G
	0.51	No. 227...	Y	Y	Y	1R	10R	25R	GY	GTrR	G	TrR
	0.38	No. 326...	Y	Y	Y	2R	60R	75R&G	GY	GY	G	G
	0.47	No. 327...	Y	Y	Y	Y	G	8R	GY	GY	G	G
	0.45	No. 225...	Y	Y	Y	Y	G	8R	GY	GY	G	G
0.50 to 0.60 Avg. 0.54	0.61	No. 530...	G	G	G	G	MG	MG	G	G	MG	MG
	0.57	No. 432...	G	G	G	G	MG	MG	G	G	MG	MG
	0.60	No. 531...	G	GY	GY	GY	G-60R	15R-80R	G	G	MG	MG
	0.48	No. 431...	Y	Y	Y	Y	GY	25R	GY	GY	G	G
	0.54	No. 430...	Y	Y	Y	Y	GY	12R	GY	GY	G	G
	0.49	No. 532...	Y	Y	Y	Y	5R	30R	GY	GY	GY	G
	0.49	No. 433...	Y	Y	Y	Y	5R	12R	GY	GY	GY	G
0.60 to 0.70 Avg. 0.64	0.69	No. 338...	G	G	G	G	MG	MG	GY	GY	MG	MG
	0.68	No. 236...	G	G	G	G	MG	MG	G	G	MG	MG
	0.61	No. 335...	GY	GY	GY	GY	G	8R	G	G	MG	MG
	0.63	No. 237...	GY	GY	GY	GY	G	G	G	G	MG	MG
	0.57	No. 337...	Y	Y	Y	Y	G	G	GY	GY	G	G
	0.67	No. 235...	Y	Y	Y	Y	5R	15R	GY	GY	GY	G
	0.66	No. 336...	Y	Y	Y	Y	G	G	GY	GY	G	G
	0.60	No. 238...	Y	Y	Y	Y	G	G	GY	GY	G	G
0.70 to 0.85 Avg. 0.74	0.70	No. 540...	G	G	G	G	MG	MG	G	G	MG	MG
	0.72	No. 442...	G	G	G	G	MG	MG	G	G	MG	MG
	0.79	No. 543...	G	G	G	G	MG	MG	G	G	MG	MG
	0.78	No. 441...	G	G	G	G	G	MG	G	G	MG	MG
	0.70	No. 542...	G	G	G	GY	G	G	G	G	MG	MG
	0.74	No. 443...	G	GY	GY	G	G	G	G	G	MG	MG
	0.76	No. 541...	G	G	G	GY	MG	MG	G	G	MG	MG
	0.76	No. 440...	G	G	G	G	MG	MG	G	G	MG	MG
0.80 to 1.00 Avg 0.90	1.05	No. 348...	G	G	G	G	MG	MG	G	G	MG	MG
	0.81	No. 248...	G	G	G	G	MG	MG	G	G	MG	MG
	0.88	No. 347...	G	G	G	G	MG	MG	G	G	MG	MG
	0.95	No. 246...	G	G	G	G	MG	MG	G	G	MG	MG
	0.88	No. 346...	G	G	G	GY	G	G	G	G	MG	MG
	0.81	No. 245...	GY	G	G	GY	G	G	G	G	MG	MG
	0.84	No. 345...	Y	Y	Y	Y	G	G	G	G	G	G
	0.96	No. 247...	GY	GY	GY	Y	G	G	GY	G	G	G
1.60 to 1.80	1.75	No. 350...	G	G	G	G	MG	MG	G	G	MG	MG
	1.69	No. 252...	G	G	G	G	MG	MG	G	G	MG	MG
	1.75	No. 352...	G	G	G	G	MG	MG	G	G	MG	MG
Avg. 2.76	2.80	No. 397...	G	G	G	G	MG	MG	G	G	MG	MG
	2.72	No. 298...	G	G	G	G	MG	MG	G	G	MG	MG
12–14% Cr, cold drawn.......		No. 001...	M	M	M	MG	M	M	SY	SY	MG*	MG*
12–14% Cr, air quenched....		No. 002...	M	M	M	MG	M	M	SY	SY	MG	MG
18% Cr, 8% Ni...		No. 003...	M	M	M	M	M	M	M	M	M	M
Copper covered (7.42 oz. per sq. ft.).......		No. 020...	Gn	Gn	Gn	Gn	Gn	Gn	Br	Br	Br	Br
Lead coated (1.48 oz. per sq. ft.)..........		No. 040...	20PHR	35R+Y	30R+Y	30R+Y	15PHR	15PHR	50PHY	50PHY	30PHY	15PHR

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of

OF FARM FIELD FENCE SPECIMENS.

rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pin-
of a better observation; MG = intermediate between M and G; GY = predominately gray but showing indication of Y; SY
centages. Where two values are shown separated by a dash (50R-80R) the first applies to the line wires and the second to the
the bottom wires of the fence.

Ithaca, N.Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.		Coating Group	Average Coating, oz. per sq. ft. of surface[a]	Fence
6.95 yr.	7.94 yr.	6.90 yr.	7.85 yr.	6.87 yr.	7.80 yr.	6.91 yr.	7.85 yr.			
100R&G	80R&G	G	G	12R	20R	G	G	0.20 to 0.30 Avg. 0.28	0.27	No. 512
85R&G	50R&G	G10Y	G15Y	5R	25R-GY	G	G		0.30	No. 410
15R&G	75R&G	G	G	GY	2R	G	G		0.28	No. 411
90R&G	100R&G	G	G	2R	3R	G	G		0.29	No. 510
75R&G	80R&G	G10Y	G15Y	GY	5R	G	G		0.29	No. 412
50R&G	80R&G	G	G	2R	4R	G	G		0.24	No. 511
95R&G	90R	G	G	12R	17R	G	G	0.25 to 0.35 Avg. 0.30	0.25	No. 315
85R	100R	G	G	5R	12R	G1Y	G1Y		0.28	No. 215
6R-10R	60R	G	G	GY	1R	G	G		0.38	No. 317
40R	80R	5Y	G10Y	1R	3R	G	G		0.32	No. 316
10R-50R	60R	G	G	GY	GY	G	G		0.30	No. 216
75R&G	60R&G	G	G	3R	7R	G	G	0.35 to 0.45 Avg. 0.38	0.36	No. 520
35R&G	70R&G	G10Y	G10Y	3R	5R	G	G		0.35	No. 422
90R&G	50R	G	G	GY	1R	G	G		0.31	No. 423
1R-50R	50R&G	G	G	GY	2R	G	G		0.44	No. 522
20R-100R	60R&G	G	G	5R	8R	G	G		0.38	No. 521
G-25R	G-100R	G	G	1R	3R	G	G		0.47	No. 421
G	5R	5Y	5Y	1R	5R	G	G	0.45 to 0.55 Avg. 0.46	0.44	No. 325
1R	1R	5Y	10Y	5R	5R	G	G		0.50	No. 228
2R	4R	5Y	10Y	GY	3R	G	G		0.51	No. 227
5R	50R	G	G	1R	2R	G	G		0.38	No. 326
G	1R	G	G	GY	1R	G	G		0.47	No. 327
3R	1R	G	G	GY	1R	G	G		0.45	No. 225
M	M	MG	MG	G	G	MG	MG	0.50 to 0.60 Avg. 0.54	0.61	No. 530
M	M	MG	MG	G	G	MG	MG		0.57	No. 432
G	G-10R	MG	G	G	G	MG	MG		0.60	No. 531
G	1R	G	G	1R	2R	G	G		0.48	No. 431
G	1R	G2Y	G2Y	GY	3R	G	G		0.54	No. 430
G	G-10R	G5Y	G5Y	GY	1R	G	G		0.49	No. 532
G	G	G5Y	G5Y	1R	3R	G	G		0.49	No. 433
M	M	MG	MG	G	G	MG	MG	0.60 to 0.70 Avg. 0.64	0.69	No. 338
M	M	MG	MG	G	G	MG	MG		0.68	No. 236
G	G	G	G	G	G	MG	MG		0.61	No. 335
G	MG	G	G	G	G	MG	MG		0.63	No. 237
G	G	G	G	1R	2R	G	G		0.57	No. 337
G	2R	5Y	5Y	1R	4R	G	G		6.67	No. 235
G	G	5Y	10Y	1R	4R	G	G		0.66	No. 336
G	G	5Y	10Y	3R	5R	G	G		0.60	No. 238
M	M	MG	MG	G	G	MG	MG	0.70 to 0.85 Avg. 0.74	0.70	No. 540
M	M	MG	MG	G	G	MG	MG		0.72	No. 442
MG	MG	MG	MG	G	G	MG	MG		0.79	No. 543
M	M	MG	MG	G	G	MG	MG		0.78	No. 441
G	G	MG	MG	G	G	MG	MG		0.70	No. 542
MG	G	MG	MG	G	G	MG	MG		0.74	No. 443
MG	MG	MG	MG	G	G	G	MG		0.76	No. 541
MG	MG	MG	MG	G	G	MG	MG		0.76	No. 440
M	M	MG	MG	G	G	MG	MG	0.80 to 1.00 Avg. 0.90	1.05	No. 348
M	M	MG	MG	G	G	MG	MG		0.81	No. 248
M	M	G	G	G	G	MG	MG		0.88	No. 347
MG	MG	G	G	G	G	MG	MG		0.95	No. 246
MG	G	MG	MG	G	G	MG	MG		0.88	No. 346
MG	MG	G	MG	G	G	MG	MG		0.81	No. 245
G	G	G	G	GY	GY	G	G		0.84	No. 345
G	G	G	G	GY	2R	G	G		0.96	No. 247
M	M	MG	MG	G	G	MG	MG	1.60 to 1.80	1.75	No. 350
M	M	MG	MG	G	G	MG	MG		1.69	No. 252
M	M	G	G	G	G	G	G		1.75	No. 352
M	M	MG	MG	G	G	MG	MG	Avg. 2.76	2.80	No. 397
M	M	MG	MG	G	G	MG	MG		2.72	No. 298
M*	MG*	30SR	35SR	50SR	50SR	35SR-45SR	60SR-80SR	12-14% Cr, cold drawn		No. 001
M*	M	15SR	20SR	30SR	20SR	10SR-35SR	10SR-35SR	12-14% Cr, air quenched		No. 002
M	M	M5G	MG	5SY*	5SY	M5G	MG	18% Cr, 8% Ni.		No. 003
Br	Br	Br	Br	Br	Br	Br	Br	Copper covered (7.42 oz. per sq. ft.)........		No. 020
15R	5R	25R-30SR	35SR-2SR	20PHSR	20RPHSR	40SR-5SR	45SR-5SR	Lead coated (1.48 oz. per sq. ft.)		No. 040

unfabricated wire, fence or barbed wire of the specific wire lot number.

TABLE IV.—REPORT OF INSPECTIONS OF CHAIN LINK SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pinholes; B, Br, Gn, respectively, signify corroded to a black, brown, or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; MG = intermediate between M and G; GY = predominately gray but showing indication of Y; Asterisk (*) = sample disappearance—probably stolen; R+Y = indistinguishable proportions of R and Y.

All 200 series wires are 9 gage. Lead-coated wire, 9 gage. Corrosion-resistant steel, 14 gage.

All 100 series wires are 6 gage. Copper-covered wire 0.128d.

Zinc Coating, oz. per sq. ft of surface, by stripping test	Fence	Pittsburgh, Pa.				Sandy Hook, N. J.				Bridgeport, Conn.			
		6.48 yr.	6.95 yr.	7.48 yr.	7.93 yr.	6.44 yr.	6.90 yr.	7.44 yr.	7.91 yr.	6.45 yr.	6.90 yr.	7.44 yr.	7.90 yr.
0.29	No. E280[a]	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R
0.52	No. E281	100R	100R	100R	100R	100R	100R	100R	100R	99R	100R	100R	100R
0.37	No. E282	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R
1.22	No. E185	100R	100R	100R	100R	GY	GY	GY	Y	GY	GY	GY	Y
1.13	No. E285	100R	100R	100R	100R	GY	GY	GY	Y	GY	GY	GY	Y
2.92	No. E290	G	GY	5R	30R	G	G	G	G	G	G	G	G
2.09	No. E291	90R	90R	98R	100R	G	G	G	G	G	G	G	G
1.60	No. H280[a]	98R	99R	99R	100R	G	G	GY	7R	GY	GY	GY	1R
1.83	No. H185	98R	100R	100R	100R	GY	GY	GY	GY	GY	GY	GY	Y
1.60	No. H186	95R	100R	100R	100R	G	G	G	G	G	GY	GY	GY
1.61	No. H187	99R	98R	99R	100R	G	G	G	GY	GY	GY	GY	GY
1.55	No. H188	95R	100R	100R	100R	GY	GY	GY	GY	GY	GY	GY	Y
1.36	No. H285	98R	100R	100R	100R	GY	G	GY	5R	GY	GY	GY	Y
1.97	No. H286	95R	100R	100R	100R	GY	GY	GY	5R	GY	GY	GY	GY
1.46	No. H287	85R	100R	100R	100R	GY	GY	GY	10R	GY	GY	GY	GY
1.74	No. H288	100R	100R	100R	100R	GY	GY	GY	GY	GY	GY	GY	GY
1.40	No. H289[b]	100R	100R	100R	100R	G	G	G	G	GY	G	G	G
4.21	No. H290	Y	Y	TrR	25R	G	G	G	G	G	G	G	G
Lead-coated L050 (1.75 oz. per sq. ft.)		5PHR	30PHR	25R+Y	20R	50R+Y	50R+Y	60R+Y	60R+Y	GY	GY	GY	10R+Y
Copper-covered K030 (8.52 oz. per sq. ft.)		....	....	....	....	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn
Corrosion-resistant steel J011		B	B	B	B	MG	MG	MG	M	M	M	M	MG

Zinc Coating, oz. per sq. ft. of surface, by stripping test	Fence	State College, Pa.				Lafayette, Ind.		Ithaca, N. Y.		Santa Cruz, Calif.		Davis, Calif.	
		5.42 yr.	5.88 yr.	6.42 yr.	6.87 yr.	7.03 yr.	8.00 yr.	6.95 yr.	7.94 yr.	6.70 yr.	7.85 yr.	6.91 yr.	7.85 yr.
0.29	No. E280[a]	50R	90R	100R	100R	90R	100R	90R	100R	GY	GY	G	G
0.52	No. E281	GY	GY	GY	TrR	10R	30R	1R	20R	G	G	G	G
0.37	No. E282	Y	GYTrR	Y	30R	90R	100R	30R	80R	G	GY	G	G
1.22	No. E185	G	G	G	G	G	G	MG	MG	G	MG	MG	MG
1.13	No. E285	G	G	G	G	G	G	MG	M	G	MG	MG	MG
2.92	No. E290	G	G	G	G	MG	MG	M	M	MG	MG	MG	MG
2.09	No. E291	G	G	G	G	MG	MG	MG	M	G	MG	MG	MG
1.60	No. H280[a]	G	G	G	G	MG	G	MG	MG	G	MG	G	MG
1.83	No. H185	G	G	G	G	G	G	MG	MG	MG	MG	MG	MG
1.60	No. H186	G	G	G	G	MG	MG	MG	MG	G	MG	MG	MG
1.61	No. H187	G	G	G	G	MG	MG	MG	MG	G	MG	G	G
1.55	No. H188	G	G	G	G	MG	MG	MG	MG	MG	MG	MG	MG
1.36	No. H285	G	G	G	G	G	G	MG	G	G	G	MG	MG
1.97	No. H286	G	G	G	G	G	G	MG	MG	MG	MG	MG	MG
1.46	No. H287	G	G	G	G	G	MG	MG	MG	MG	MG	MG	MG
1.74	No. H288	G	G	G	G	MG	MG	MG	MG	G	MG	MG	MG
1.40	No. H289[b]	G	G	G	G	MG	MG	M	M	MG	MG	MG	MG
4.21	No. H290	G	G	G	G	MG	MG	M	MG	MG	MG	MG	MG
Lead-coated L050 (1.75 oz. per sq. ft.)		70R+Y	70R+Y	70R+Y	70R+Y	5PHR	10PHR	5R	2R	15SR	15SR	20SR	25SR
Copper-covered K030 (8.52 oz. per sq. ft.)		Gn	Gn	Gn	Gn	Gn	Gn	Br	Br	Br	Br	Br	Br
Corrosion-resistant steel J011		M	M	M	M	M	M	M	M	MG	MG	MG	MG

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[a] E numbers—coating applied before weaving. H numbers—coating applied after weaving.

[b] While this sample has an H number, its appearance indicates that it was galvanized before weaving.

TABLE V.—REPORT OF INSPECTIONS OF WIRE STRAND SPECIMENS.

Abbreviations and symbols used to designate appearance or states of corrosion: M = metallic; G = gray; Y = yellowed, or rust stained, but not showing actual rough rust of base metal; R = rust of base metal; PHR, PHY = rust or yellowed in pinholes; B, Br, Gn, respectively signify corroded to a black, brown, or green appearance; D = dark (dirt or soot) to the exclusion of a better observation; MG = intermediate between M and G; GY = predominately gray but showing indication of Y; R+Y = indistinguishable proportions of R and Y.

Zinc Coating, oz. per sq. ft. of surface	Strand	Pittsburgh, Pa.				Sandy Hook, N. J.				Bridgeport, Conn.				State College, Pa.				Lafayette, Ind.	
		6.48 yr.	6.95 yr.	7.48 yr.	7.93 yr.	6.44 yr.	6.90 yr.	7.44 yr.	7.91 yr.	6.45 yr.	6.90 yr.	7.44 yr.	7.90 yr.	6.30 yr.	6.76 yr.	7.30 yr.	7.75 yr.	7.03 yr.	8.00 yr.
0.69	No. D345	40R	90R	100R	100R	G	G	G	G	G	G	G	G	G	G	G	G	MG	MG
0.88	No. D346	40R	80R	100R	100R	G	G	G	G	G	G	GY	G	G	G	G	G	MG	MG
0.87	No. D347	100R	100R	100R	100R	GY	GY	GY	GY	G	G	GY	G	G	G	GY	G	MG	MG
0.93	No. D348	70R	100R	100R	100R	G	G	G	G	G	G	G	G	G	G	G	G	MG	M
1.10	No. D360	50R	100R	100R	100R	G	G	G	G	G	G	G	G	G	G	G	G	MG	MG
1.17	No. D361	95R	98R	100R	100R	G	G	GY	G	G	G	GY	G	G	G	G	G	MG	MG
1.03	No. D362	90R	98R	100R	100R	GY	GY	GY	GY	GY	GY	GY	GY	G	G	GY	GY	MG	MG
1.51	No. D365	Y	20R	50R	50R	G	G	G	G	G	G	G	G	G	G	G	G	MG	MG
1.39	No. D366	20R	30R	50R	30R	G	G	G	G	G	G	G	G	G	G	G	G	MG	MG
1.32	No. D367	5R	20R	80R	80R	GY	GY	GY	GY	GY	GY	GY	GY	G	G	GY	GY	G	G
1.71	No. D371	10R	20R	40R	40R	G	G	G	G	G	GY	G	G	G	G	G	G	MG	MG
2.47	No. D375	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	MG	MG
Lead Coating (1.96 oz. per sq. ft.)	No. D045	B	B	25R-B	25R-B	80R+Y	95R+Y	90R+Y	90R+Y	20R+Y	40R+Y	20R+Y	35R+Y	50R+Y	60R+Y	80R+Y	70R+Y	45PHR	45PHR

Zinc Coating, oz. per sq. ft. of surface	Strand	Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
		6.93 yr.	7.90 yr.	6.92 yr.	7.89 yr.	6.95 yr.	7.94 yr.	6.90 yr.	7.85 yr.	6.87 yr.	7.80 yr.	6.91 yr.	7.85 yr.
0.69	No. D345	G	G	MG	MG	M	M	MG	G	G	G	MG	G
0.88	No. D346	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
0.87	No. D347	G	G	MG	MG	MG	MG	MG	G	G	G	MG	G
0.93	No. D348	G	G	MG	MG	M	M	G	G	G	G	MG	MG
1.10	No. D360	G	G	MG	MG	M	M	MG	G	G	G	MG	MG
1.17	No. D361	G	G	MG	MG	MG	MG	G	G	G	G	MG	MG
1.03	No. D362	G	G	MG	MG	MG	MG	MG	MG	G	G	MG	MG
1.51	No. D365	G	G	MG	MG	MG	MG	G	G	G	G	MG	G
1.39	No. D366	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
1.32	No. D367	G	G	MG	MG	MG	MG	MG	MG	G	G	MG	MG
1.71	No. D371	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
2.47	No. D375	G	G	MG	MG	M	M	MG	MG	G	G	MG	MG
Lead Coating (1.96 oz. per sq. ft.)	No. D045	60PHY	70PHY	35R+Y	20R	25R	35R	40SR	45SR	55R+Y	80R+Y	40SR2R	45SR2R

TABLE VI.—BREAKING LOADS AND ELONGATION OF UNFABRICATED WIRE SPECIMENS.

Wire Lot	Exposure, yr.	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	Wire Lot	Exposure, yr.	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent
TESTS ON SPECIMENS EXPOSED AT BRUNOT ISLAND (PITTSBURGH, PA.)									
No. 520	6.48	1.20	95	4.3	No. 430	6.95	2.60	390	0.4
No. 520	6.95	1.20	80	1.4	No. 430	7.93	2.60	340	0.1
No. 521	6.48	1.75	100	2.0	No. 431	6.95	1.60	410	0.5
No. 521	6.95	1.75	65	0.9	No. 431	7.93	1.60	360	0.3
No. 522	6.48	1.45	140	0.0	No. 432	6.95	1.60	245	2.0
No. 522	6.95	1.45	102	0.2	No. 432	7.93	1.60	190	1.1
No. 530	6.48	1.20	145	0.8	No. 440	6.48	2.60	305	6.3
No. 530	6.95	1.20	60	0.2	No. 440	7.48	2.60	280	2.2
No. 531	6.48	1.40	90	2.5	No. 440	7.93	2.60	215	1.3
No. 531	6.95	1.40	105	0.1	No. 441	6.48	1.90	265	9.4
No. 540	6.48	1.85	85	1.3	No. 441	7.48	1.90	205	5.1
No. 540	6.95	1.85	65	0.2	No. 441	7.93	1.90	190	2.5
No. 540	7.48	1.85	60	1.2	No. 442	6.48	2.00	225	5.8
No. 541	6.48	2.60	110	1.2	No. 442	7.48	2.00	200	2.9
No. 541	6.95	2.60	95	0.3	No. 442	7.93	2.00	170	1.2
No. 541	7.48	2.60	85	1.0	No. 443	6.48	1.90	405	1.0
No. 542	6.48	1.65	175	0.4	No. 443	7.48	1.90	315	0.2
No. 542	6.95	1.65	145	0.2	No. 443	7.93	1.90	295	0.2
No. 542	7.48	1.65	115	0.3	No. 444	6.48	2.70	325	6.9
No. 543	6.48	1.85	135	1.6	No. 444	7.48	2.70	250	4.3
No. 543	6.95	1.85	80	0.4	No. 444	7.93	2.70	245	2.8
No. 543	7.48	1.85	75	0.8	No. 495	6.48	1.90	415	0.8
No. 551	6.48	4.50	290	0.6	No. 495	7.48	1.90	360	0.2
No. 551	6.95	4.50	285	0.2	No. 495	7.93	1.90	310	0.1
No. 551	7.48	4.50	295	0.2	No. 450	6.48	2.95	620	0.4
No. 551	7.93	4.50	120	0.2	No. 450	6.95	2.95	485	0.2
No. 551	7.93	4.50	120	0.1	No. 450	7.48	2.95	455	0.3
No. 552	6.48	4.90	200	1.9	No. 450	7.93	2.95	395	0.1
No. 552	6.95	4.90	180	0.2	No. 451	6.48	4.50	390	3.5
No. 552	7.48	4.90	170	0.5	No. 451	6.95	4.50	335	2.1
No. 552	7.93	4.90	110	0.2	No. 451	7.48	4.50	335	1.8
No. 410	6.95	0.65	215	5.7	No. 451	7.93	4.50	290	1.3
No. 410	6.95	0.65	205	1.7	No. 421	6.95	1.60	210	6.2
No. 412	6.95	1.25	430	0.3	No. 421	6.95	1.60	230	3.3
No. 412	6.95	1.25	410	0.3					
No. 315	6.48	0.40	570	6.0	No. 139	7.48	1.90	1595	10.6
No. 316	6.48	1.20	745	0.9	No. 345	6.48	2.70	680	7.1
No. 317	6.48	1.40	520	8.5	No. 345	7.48	2.70	580	3.6
No. 215	7.48	0.60	810	9.4	No. 346	6.48	2.50	760	2.5
No. 216	7.48	1.30	1180	3.0	No. 346	7.48	2.50	665	1.5
No. 217	7.48	1.00	885	4.7	No. 347	6.48	2.60	585	5.4
No. 115	7.48	0.60	2145	3.9	No. 347	7.48	2.60	525	5.8
No. 117	7.48	0.70	1780	10.1	No. 348	6.48	3.20	735	0.5
No. 325	6.48	1.70	545	14.4	No. 348	7.48	3.20	630	0.6
No. 325	7.48	1.70	495	12.3	No. 245	6.48	2.40	1265	3.1
No. 326	6.48	1.40	370	7.8	No. 246	6.48	2.90	1015	10.9
No. 326	7.48	1.40	295	6.7	No. 247	6.48	2.90	1360	6.0
No. 327	6.48	1.80	815	2.2	No. 248	6.48	2.10	1245	1.4
No. 327	7.48	1.80	705	0.5	No. 296	6.48	2.50	1325	4.2
No. 329	6.48	1.80	500	11.2	No. 148	6.48	2.70	2305	5.2
No. 329	7.48	1.80	430	10.4	No. 149	6.48	2.70	1720	14.1
No. 225	6.48	1.90	1345	3.7	No. 800	6.48	3.90	2460	5.0
No. 226	6.48	1.90	950	13.0	No. 801	6.48	3.50	1220	4.0
No. 227	6.48	2.50	....	....	No. 350	6.48	5.10	555	12.2
No. 228	6.48	1.60	910	14.0	No. 350	7.48	5.10	495	9.1
No. 125	6.48	1.40	1615	14.3	No. 351	6.48	2.90	835	7.0
No. 127	6.48	1.70	2085	4.2	No. 351	7.48	2.90	720	4.5
No. 335	6.48	1.60	735	1.9	No. 352	6.48	3.90	1125	0.6
No. 335	7.48	1.60	640	1.3	No. 352	7.48	3.90	970	0.2
No. 336	6.48	2.70	555	9.3	No. 250	6.48	3.90	1330	8.0
No. 336	7.48	2.70	495	10.5	No. 251	6.48	3.90	1750	1.2
No. 337	6.48	2.50	585	7.9	No. 252	6.48	4.50	1025	9.6
No. 337	7.48	2.50	510	7.8	No. 151	6.48	3.90	2880	1.2
No. 338	6.48	2.00	730	0.7	No. 305	7.48	0	540	1.3
No. 338	7.48	2.00	620	0.5	No. 306	7.48	0	380	10.7
No. 235	7.48	2.60	1285	3.7	No. 101	6.48	0	1810	3.3
No. 236	7.48	2.00	1035	1.6	No. 102	6.48	0	1625	8.8
No. 237	7.48	1.80	1125	2.6	No. 105	6.48	0	2090	2.0
No. 238	7.48	2.50	1205	3.4	No. 106	6.48	0	1870	1.9
No. 239	7.48	2.60	850	15.1	No. 040	6.48	0.9	1850	6.4
No. 135	7.48	2.60	2105	3.1	No. 041	6.48	0.9	1085	8.4
No. 138	7.48	2.00	1635	14.4	No. 042	6.48	0.9	695	6.4
					No. 043	6.48	0.9	275	6.8

Continued on page 84

TABLE VI.—*Concluded.*

Wire Lot	Exposure, yr.	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent	Wire Lot	Exposure, yr.	First Rust, yr.	Breaking Load, lb.	Elongation in 10 in., per cent
TESTS ON SPECIMENS EXPOSED AT SANDY HOOK, N. J.									
No. 510	6.90	1.70	295	0.23	No. 327	6.44	3.80	1040	5.37
No. 511	6.90	1.70	150	5.17	No. 329	6.44	3.80	675	13.47
No. 512	6.90	1.50	190	3.07	No. 225	6.44	3.90	1535	4.40
No. 410	6.90	1.80	425	9.53	No. 226	6.44	3.90	1115	13.33
No. 411	6.90	1.80	480	2.47	No. 227	6.44	4.40	1505	6.40
No. 412	6.90	2.50	660	0.67	No. 228	6.44	2.90	1040	15.10
No. 315	6.44	1.60	790	8.73	No. 125	6.44	3.40	1740	15.17
No. 316	6.44	2.70	965	3.17	No. 127	6.44	3.90	2505	5.23
No. 317	6.44	3.70	710	13.63	No. 530	6.44	2.90	300	9.07
No. 215	6.44	1.80	1070	11.23	No. 530	7.91	2.90	235	4.97
No. 216	6.44	2.70	1460	5.90	No. 531	6.44	4.70	455	0.47
No. 217	6.44	2.80	1075	7.40	No. 531	7.91	4.70	365	0.27
No. 115	6.44	1.70	2485	4.93	No. 430	6.44	4.40	745	2.87
No. 117	6.44	2.70	2080	9.67	No. 430	7.91	4.40	615	0.87
No. 520	6.44	2.70	215	9.33	No. 431	6.44	3.70	765	3.17
No. 520	7.91	2.70	185	7.30	No. 431	7.91	3.70	680	1.90
No. 521	6.44	2.90	215	11.50	No. 432	6.44	no R	555	7.50
No. 521	7.91	2.90	185	8.17	No. 432	7.91	6.50	445	6.77
No. 522	6.44	2.90	370	0.37	No. 501	6.90	0	210	0.27
No. 522	7.91	2.90	315	0.23	No. 506	6.90	0	225	0.17
No. 421	6.44	2.80	410	11.47	No. 507	6.90	0	185	0.20
No. 421	7.91	2.80	350	9.03	No. 400	6.90	0	300	8.40
No. 422	6.44	2.90	435	12.27	No. 401	6.90	0	250	3.80
No. 422	7.91	2.90	405	11.07	No. 405	6.90	0	280	8.50
No. 423	6.44	2.70	350	13.90	No. 406	6.90	0	310	10.57
No. 423	7.91	2.70	....	....	No. 101	6.44	0	1965	3.87
No. 282	6.44	2.90	1205	10.50	No. 102	6.44	0	1730	10.13
No. 282	7.91	2.90	1180	8.73	No. 105	6.44	0	2330	3.33
No. 325	6.44	3.80	695	16.07	No. 106	6.44	0	2195	1.7
No. 326	6.44	3.80	610	16.87					
TESTS ON SPECIMENS EXPOSED AT BRIDGEPORT, CONN.									
No. 315	6.45	1.70	815	10.10	No. 226	6.45	3.90	1115	15.37
No. 316	6.45	2.50	1025	4.63	No. 227	6.45	4.40	1565	4.73
No. 317	6.45	2.80	710	10.40	No. 228	6.45	3.80	1085	15.83
No. 215	6.45	1.80	1125	13.50	No. 125	6.45	3.70	1795	13.97
No. 216	6.45	2.80	1510	6.97	No. 127	6.45	4.00	2490	4.63
No. 217	6.45	2.70	1030	8.43	No. 530	6.45	5.40	270	6.70
No. 115	6.45	1.70	2585	5.50	No. 530	7.90	5.40	250	6.77
No. 117	6.45	2.70	2100	10.60	No. 531	6.45	4.70	440	0.53
No. 520	6.45	2.50	245	12.93	No. 531	7.90	4.70	385	0.50
No. 521	6.45	3.40	260	13.87	No. 430	6.45	4.90	805	4.33
No. 522	6.45	3.40	430	0.30	No. 430	7.90	4.90	715	0.97
No. 421	6.45	2.70	425	13.37	No. 431	6.45	3.50	790	4.33
No. 422	6.45	2.70	465	13.67	No. 431	7.90	3.50	715	3.00
No. 423	6.45	2.50	365	14.53	No. 432	6.45	5.40	515	4.93
No. 282	6.45	2.80	1280	11.33	No. 432	7.90	5.40	465	6.77
No. 325	6.45	3.90	715	16.10	No. 040	6.45	1.40	1870	9.07
No. 326	6.45	2.90	640	13.80	No. 041	6.45	1.40	1090	11.30
No. 327	6.45	3.90	1065	5.73	No. 042	6.45	1.40	715	9.03
No. 329	6.45	3.80	690	13.17	No. 043	6.45	1.40	3.5	15.30
No. 225	6.45	3.90	1580	4.53	...	....	....	....	....
TESTS ON SPECIMENS EXPOSED AT STATE COLLEGE, PA.									
No. 510	6.30	5.70	495	0.9	No. 315	7.30	4.00	850	11.8
No. 510	7.30	5.70	460	....	No. 316	7.30	5.70	1075	5.1
No. 511	6.30	4.70	250	15.8	No. 317	7.30	6.75	810	15.2
No. 511	7.30	4.70	250	14.6	No. 215	7.30	4.00	1140	13.7
No. 512	6.30	4.50	280	15.1	No. 216	7.30	5.70	1590	5.6
No. 512	7.30	4.50	285	14.0	No. 217	7.30	5.50	1160	8.0
No. 410	6.30	4.50	570	13.5	No. 115	7.30	4.30	2650	5.6
No. 410	7.30	4.50	540	15.3	No. 117	7.30	4.70	2190	9.6
No. 411	6.30	5.50	695	2.9	No. 040	6.30	1.30	1885	8.6
No. 411	7.30	5.50	650	5.5	No. 041	6.30	1.30	1105	11.5
No. 412	6.30	5.70	850	6.0	No. 042	6.30	1.30	720	11.2
No. 412	7.30	5.70	795	2.6	No. 043	6.30	1.30	315	15.2

TABLE VII.—LOSS OF WEIGHTS OF ZINC COATED WIRES.

(Tests on unfabricated wires weighed and measured before exposure.)
Losses of Weight in ounces per square foot.

Gage of Wire	Group A[a]			Group B[a]			Group C[a]			Averages of Like Gages
	Wire Lot	Rack Exposure		Wire Lot	Rack Exposure		Wire Lot	Rack Exposure		
		West Side	East Side		West Side	East Side		West Side	East Side	
STATE COLLEGE, PA. EXPOSURES (6.30 YR.)										
6	No. 148	0.379 0.361	0.362 0.377							0.370
9				No. 247	0.395 0.377	0.356 0.373	No. 248	0.306 0.311	0.300 0.300	0.340
11	No. 346	0.382 0.382	0.379 0.363	No. 345	0.378 0.369	0.374 0.374	No. 348	0.318 0.312	0.311 0.311	0.354
14½	No. 542	0.360 0.385	0.384 0.375	No. 541	0.366 0.371	0.376 0.376	No. 540	0.316 0.295	0.327 0.311	0.354
	Average...	0.375	0.370	Average...	0.376	0.371	Average...	0.309	0.310	

[a] By reference to the published referee tests results, the wires listed under Group A, (or B or C) will be found to be closely alike as regards base metal composition and coating characteristics.

gages are shown in Table H. In calculating elapsed time since rusting began, all the uncoated wires were assumed to have started to rust immediately on exposure. In the case of the zinc-coated specimens, the time of exposure since first rust was calculated by subtracting from the total time of exposure the time required for first rust to appear as determined from the records of visual inspections. The table also shows for each test specimen the calculated tensile strength loss in per cent per year of exposure since first rust.

In Fig. 2 the data from Table H are plotted to show the loss in tensile strength with different periods of exposure since first rust. All the test data are included except some few initial tests made before rusting occurred or so shortly after rusting started that the results were not significant. Through the plotted points a trend line for each wire gage was drawn by eye with the additional aid of short-cut statistical methods.

In the case of the No. 14½-gage wires the additional data obtained since the last report did not seem to alter the trend line previously shown in the 1943 *Proceedings*.[4] In the case of the No. 12½-gage wires the more recent data necessitated a slight change in the trend line. The former trend line is shown as a broken line in Fig. 2.

The progressive loss of strength of zinc-coated wires after the zinc coatings were gone was about the same (or slightly slower) than the loss of strength experienced by uncoated wires. This is substantiated by the curves of Fig. 2 which show that the encircled points (copper-bearing uncoated steel wires) are in general not out of line with the nonencircled dots (copper-bearing zinc-coated steel wires).

Data from other gage wires removed from Pittsburgh were not sufficient to warrant a revision of the results previously published.

Corrosion at the other test sites has not progressed sufficiently to make possible extensive comparisons of tensile strength loss.

Respectfully submitted on behalf of the Wire Test Inspection Committee,

C. D. HOCKER,
Chairman.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-5, jointly with Committee B-8 on Electrodeposited Metallic Coatings, presented to the Society through the Administrative Committee on Standards a proposed revision of the Tentative Method of Test for Local Thickness of Electrodeposited Coatings (A 219 - 40 T). This recommendation was accepted by the Standards Committee on August 27, 1945, and the revised method appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part I, under the designation A 219 - 45 T.

REPORT OF COMMITTEE A-10

ON

IRON-CHROMIUM, IRON-CHROMIUM-NICKEL AND RELATED ALLOYS*

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys held a meeting in New York, N. Y., on June 27, 1944. The activities of the committee since that time have been conducted largely by correspondence.

Some changes in committee personnel occurred during the year resulting in the present membership of 86, of whom 37 are classified as producers, 36 as consumers, and 13 as general interest members.

W. G. Hubbell of Ryan Aeronautical Co. and J. E. Seymour of Northrop Aircraft, Inc., were admitted to membership representing the Pacific Coast Aircraft War Production Council. H. S. Schaufus returned to the committee as representative of Eastern Stainless Steel Corp. with his associate I. C. Clingan.

Subsequent to the Annual Meeting, Committee A–10 presented as joint sponsor with Committee A-1 on Steel, the following recommendations to the Society through Committee E-10 on Standards:

New Tentative Specifications for:

Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 – 44 T) and Emergency Alternate Provisions EA – A 268,

Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 44 T) and Emergency Alternate Provisions EA – A 269,

Seamless and Welded Austenitic Stainless Steel Tubing for Dairy and Food Industry (A 270 – 44 T) and Emergency Alternate Provisions EA – A 270, and

Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 44 T) and Emergency Alternate Provisions EA – A 271.

These recommendations were accepted[1] by Committee E-10 on October 25, 1944, and the new tentative specifications and emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part I.

On December 27, 1944, the Standards Committee accepted[1] the following recommendations of Committee A-10:

Tentative Specifications for:

Hot-Rolled and Cold-Finished Corrosion-Resisting Bars (A 276 – 44 T),

Tentative Method of:

Total Immersion Testing of Stainless Steels (A 279 – 44 T),[2]

Revision of Tentative Recommended Practice for:

Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 – 43 T), and

Withdrawal of Emergency Alternate Provisions in the

Standard Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate,

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* Presented at the Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting these recommendations to Committee E-10 on Standards, Committee A-10 reported the following results of the letter ballot vote from a committee membership of 81: A 268 and A 269, affirmative 43, negative 0, ballots marked "not voting" 12; A 270, affirmative 40, negative 0, ballots marked "not voting" 15; A 271, affirmative 41, negative 0, ballots marked "not voting" 14; A 276, affirmative 43, negative 4, ballots marked "not voting" 8; A 279, affirmative 52, negative 0, ballots marked "not voting" 4; A 262, affirmative 51, negative 1, ballots marked "not voting" 3.

[2] 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Sheet, and Strip, for Fusion-Welded Unfired Pressure Vessels (EA – A 240a).

These new and revised tentatives also appear in the 1944 Book of A.S.T.M. Standards, Part I, except Method A 279 which is appended hereto.[2]

EMERGENCY ALTERNATE PROVISIONS

At present no changes are contemplated in Emergency Alternate Provisions EA – A 167a and EA – A 177 applying to the Standard Specifications for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 44) and for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 – 44), respectively.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Classification of Data (E. F. Cone, chairman; Russell Franks, secretary) is compiling a set of Tables of Data on Cast Corrosion- and Heat-Resisting Chromium and Chromium-Nickel Steels with the cooperation of the Alloy Castings Institute. The information necessary for preparation of the data should be available by the end of the year.

Subcommittee IV on Methods of Corrosion Testing (F. L. LaQue, chairman; Arba H. Thomas, secretary) prepared the revised Tentative Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 – 44 T) and a new Tentative Method of Total Immersion Testing of Stainless Steels (A 279 – 44 T)[2], which, as mentioned earlier in the report, were accepted by Committee E-10 during the year.

Other activities consisted of working out final details of proposed atmospheric corrosion tests on stainless steels through subgroups appointed to handle particular phases of the program. The subcommittee prepared, also, for the Army Ordnance Dept., Frankford Arsenal, a summary of opinions from producers and users of stainless steels concerning the practice of passivation by treatment with nitric acid solutions. The principal continuing activity of the subcommittee is the proposed program of atmospheric corrosion tests of stainless steels. Additional details need to be worked out before the procurement of test sites, test racks, and specimens. Exposure of specimens is not likely to begin until next year. In connection therewith, E. S. Taylerson with C. P. Larrabee as alternate, has been appointed by the chairman Mr. LaQue to represent Committee A-10 on Subcommittee VII of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys which subcommittee will correlate data on weather and climatology in connection with the corrosion of metals and alloys.

Subcommittee V on Mechanical Testing (F. T. Olt, chairman) as a result of a round-robin series of tension tests on work-hardened metal, prepared a report entitled "Cooperative Study of Effect of Rate of Strain on the Tensile Properties of Stainless Sheets," which was published as an Appendix to the 1944 Report of Committee A-10.[4]

A second round-robin tension testing program, dealing with the effect of specimen preparation, has been completed, and a report thereon is in preparation.

Subcommittee VI on Metallography (Russell Franks, chairman) has been inactive during the year. It is expected that a new program of work will be developed in connection with carbide and other phase identification in austenitic steels and also in plain chromium steels.

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[3] See Editorial Note, p. 90.

[4] *Proceedings*, Am. Soc. Testing Mats, Vol. 44, p. 133 (1944).

Subcommittee VIII on Specifications for Bars, Forgings, and Wire (J. K. Findley, chairman) prepared the new Tentative Specifications for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (A 276 – 44 T) which, as indicated earlier in this report, were accepted by Committee E-10 on December 27, 1944.

The subcommittee is now preparing specifications for corrosion - resisting spring wire.

Subcommittee IX on Specifications for Flat Products (C. C. Snyder, chairman) recommended the withdrawal of Emergency Alternate Provisions EA – A 240a applying to the Standard Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip, for Fusion-Welded Unfired Pressure Vessels (A 240 – 43) which recommendation has been accepted by Committee E-10.

Subcommittee X on Specifications for Castings (J. J. Kanter, chairman) collaborated with Subcommittee V of Committee B-4 on Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys in the prepartion of the Tentative Specifications for Chromium-Nickel-Iron Alloy Castings (25–12 Class) for High-Temperature Service (B 190 – 44 T)[5] which were accepted by the Society at the 1944 Annual Meeting. Inasmuch as these specifications are under the joint jurisdiction of Committee A-10 and Committee B-4, they were subsequently approved by letter ballot vote of Committee A-10 as follows: From a membership of 81, 55 members returned their ballots, 42 of whom voted affirmatively, 1 negatively, and 12 members marked their ballots "not voting."

Recently proposals have been made to Committee A-10 looking toward revision of the requirements for physical properties and chemical composition in the Standard Specifications for Chromium-Nickel Alloy-Steel Castings (A 222 – 39) which recommendations have been referred to Subcommittee X for study. A letter ballot on the proposed changes indicated the desirability of awaiting a report from Subcommittee I whose work on the compilation of physical properties for the alloys covered by Specifications A 222, it is anticipated, will furnish a basis for a general review of the specification limits.

Subcommittee XI on Specifications for Tubular Products (J. J. B. Rutherford, chairman) collaborated with members of Subcommittee IX of Committee A-1 on Steel in the preparation of the four new tentative specifications for stainless steel tubing for various applications which as indicated earlier in this report were accepted by Committee E-10.

The joint subcommittee also standardized the chemical composition of the several grades of corrosion-resisting steels used in tubular products by making the composition ranges in the Standard Specifications for Seamless Alloy-Steel Boiler and Superheater Tubes (A 213 – 44) and for Atomic-Hydrogen-Arc-Welded and Electric-Resistance-Welded Alloy-Steel Boiler and Superheater Tubes (A 249 – 44) and in the Tentative Specifications for Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 – 44 T) compatible with the ranges in the new specifications for tubular products.

This report has been submitted to letter ballot of the committee which consists of 86 members; 67 members returned their ballots, of whom 60 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

JEROME STRAUSS,
Chairman.

H. D. NEWELL,
Secretary.

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[5] 1944 Book of A.S.T.M. Standards, Part I.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-10 recommended to the Administrative Committee on Standards that Emergency Alternate Provisions EA – A 167a and EA – A 177 applying to the Standard Specifications for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 44) and for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 – 44) be continued without revision. This recommendation was accepted by the Standards Committee on August 27, 1945.

On January 16, 1946, the Standards Committee accepted the joint recommendation of Committee A-10 and Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys that the Tentative Specifications for Chromium-Nickel-Iron Alloy Castings (25-12 Class) for High-Temperature Service (B 190 - 44 T) be revised. The revised tentative specifications appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

REPORT OF THE RESEARCH COMMITTEE
ON
FATIGUE OF METALS*

During the 1944 Annual Meeting of the A.S.T.M., in New York, N. Y., the Research Committee on Fatigue of Metals held a meeting at which the Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel was discussed and subsequently published in the annual *Proceedings*.[1]

As an outgrowth of this discussion a paper on "A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel" has been prepared by H. F. Moore and is being presented to the Society this year.[2]

At the June meeting the relation of results of tests of fatigue specimens to the selection of stress values for design of parts subjected to repeated stress in service was discussed at some length. The general opinion of those present was that while this research committee cannot consider many machine or structural parts in detail, it should try to find correlating factors between the results of laboratory tests and the performance of parts in service.

With deep sorrow the committee notes the death of Alfred V. De Forest, for many years a notable figure in the field of fatigue of metals, a hard working member of the committee, and a friend of every member. The members of this committee cherish his memory, and extend sincerest sympathy to his family.

During the year two new members have been added to the committee: J. O. Almen of the General Motors Research Laboratory, Detroit, Mich., and Reginald B. Bland, formerly with the Lockheed Aircraft Corp. and now with the technical staff of Langley Field, Va.

In accordance with a vote by letter ballot the committee is considering the matter of nomenclature and definitions of terms used in fatigue of metals studies, the following subcommittee having been appointed to study and report on this matter: R. E. Peterson (chairman), H. W. Gillett, L. H. Donnell, R. B. Bland, and R. L. Templin.

R. E. Peterson of the Westinghouse Research Laboratories has been elected vice-chairman of the research committee.

This report has been submitted to letter ballot of the committee which consists of 26 members; 20 members returned their ballots, of whom 19 have voted affirmatively, and 1 negatively.

Respectfully submitted on behalf of the committee,

H. F. MOORE.
Chairman.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 137 (1944).

[2] See p. 507.

REPORT OF JOINT RESEARCH COMMITTEE

ON

EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS

Progress Report to the Sponsor Societies

During the past year, the Joint Research Committee on Effect of Temperature on the Properties of Metals, under the sponsorship of The American Society of Mechanical Engineers and the American Society for Testing Materials, held one meeting on November 30, 1944, in New York, N. Y., during the Annual Meeting of The American Society of Mechanical Engineers.

In addition, the committee sponsored a Session on Graphitization of Steel Piping during the Annual Meeting of The American Society of Mechanical Engineers, in New York, N. Y. on December 1, 1944, comprising the following papers:

"Graphitization of Low-Carbon and Low-Carbon-Molybdenum Steels," by H. J. Kerr and F. Eberle.

"Progress Report on Graphitization of Steam Lines," by S. L. Hoyt and R. D. Williams.

"Investigation of Graphitization at Detroit," by R. M. Van Duzer, Jr., I. A. Rohrig, and Arthur McCutchan.

"A Study of Austenitic Welding for Control of Graphitization in Steel," by I. A. Rohrig.

"Graphitization of Carbon-Molybdenum Steel in High-Temperature Steam Piping," by George A. Timmons.

"Graphitization of Welded and of End-Quenched Carbon and Molybdenum Steels," by G. V. Smith and S. H. Brambir.

The six papers and the discussion have been published by the A.S.M.E. in a special compilation, dated September, 1945, under the title "Graphitization of Steel Piping."

Finances:

There appears in Table I a summary of the administration of committee funds during the period from June 26, 1944 to June 30, 1945.

TABLE I.—SUMMARY OF RECEIPTS AND EXPENDITURES OF COMMITTEE FUNDS.

Balance as of June 26, 1944 shown in 1944 report		$8654.58
	RECEIPTS	
1944		
September	Interest on funds (10/1/43 to 9/30/44)	37.79
		$8692.37
	EXPENDITURES	
1944		
June	Printing Piping Papers	$69.97
Balance on hand, June 30, 1945		$8622.40

Organization and Membership:

There have been two additions to the membership of the committee during the year. V. T. Malcolm, of the Chapman Valve Manufacturing Co., formerly a member of the committee, has been added to the committee's membership. Also Henry North, of the Douglas Aircraft Co., Inc., has been appointed to membership to represent the West Coast aircraft manufacturers in the work of the committee.

Research Projects:

Project No. 29 on Stability of Steels as Affected by Temperature (J. J. Kanter, chairman).—This project is active in the general field of graphitization, dealing especially with graphitization of steel castings.

Respectfully submitted on behalf of the Joint Research Committee,

N. L. MOCHEL,
Chairman.

H. J. KERR,
Vice-Chairman.
J. W. BOLTON,
Secretary.

REPORT OF JOINT COMMITTEE
ON
FILLER METAL*

The Joint A.W.S.-A.S.T.M. Committee on Filler Metal has continued the formulation of standards for filler metal. The joint committee recently presented to A.S.T.M. through Committee E-10 on Standards a proposed revision of the Tentative Specifications for Iron and Steel Arc-Welding Electrodes (A 233 – 43 T),[1] including a new Guide to A.W.S.-A.S.T.M. Classification of Iron and Steel Arc-Welding Electrodes. This recommendation was approved by the A.W.S. Board of Directors on April 19, 1945, accepted[2] by A.S.T.M. Committee E-10 on May 19, 1945. The revised tentative specifications have been published under the serial designation A 233 – 45 T.[3]

A meeting of the committee was held in New York, N. Y., on June 28, 1944.

Activities of Subcommittees

Subcommittee I on Iron and Steel Arc-Welding Electrodes (J. H. Deppeler, chairman) is responsible for the revision of Tentative Specifications A 233 and the preparation of the Guide to A.W.S.-A.S.T.M. Classification of Iron and Steel Arc-Welding Electrodes, referred to above. The guide contains a discussion of the properties and use of electrodes conforming to the classifications established in the Specifications A 233 and is intended to assist the users of these electrodes. The work has been forwarded through a working group of twelve members of the subcommittee, which held four meetings and prepared proposed drafts of the specifications and guide for consideration by the entire membership of Subcommittee I. Approval of the revision was obtained at a meeting of the subcommittee, and confirmed by letter ballot vote. As indicated above the revised specifications have since been approved by the A.S.T.M. on the recommendation of the joint committee.

Subcommittee III on Aluminum and Aluminum-Alloy Filler Metal (G. O. Hoglund, chairman) prepared the Tentative Specifications for Aluminum and Aluminum-Alloy Metal Arc-Welding Electrodes (B 184 – 43 T).[1] In addition, the committee has drawn up Proposed Tentative Specifications for Gas-Welding Rods for Aluminum and Aluminum-Alloys. The final draft of these specifications is being completed and will be submitted for consideration of the main committee shortly. This work covers the primary commercial welding processes and no specific new projects are before the subcommittee. New developments in welding procedures may make it desirable to compile additional specifications, but such new developments have not yet reached the stage where filler metal requirements can be crystallized so that specifications can be drawn up.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 Book of A.S.T.M. Standards, Part I.

[2] In submitting this recommendation to Committee E-10 on Standards, the Joint Committee on Filler Metal reported results of the letter ballot vote as follows: Of a total membership of 70, 52 members returned their ballots, of whom 44 voted affirmatively, 1 negatively, and 7 members marked their ballots "not voting."

[3] 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Subcommittee IV on High-Alloy Steel Filler Metal (R. D. Thomas, chairman) held one well-attended meeting during the year, the result of which was a redrafting of the first preliminary draft of Proposed Tentative Specifications for Stainless Arc-Welding Electrodes. The modifications proposed by the members present at this meeting were later submitted to the membership of the entire subcommittee by letter ballot. The returns were, in general, affirmative, but quantitatively small. Certain negative votes were cast, accompanied by comments. Since then most of the objections raised by the negative voters have been removed, either by a proposed revision, or, in some cases, by clarification. It is expected that a third draft will be ready for submittal to letter ballot vote of the subcommittee in the near future.

Subcommittee VI on Copper and Copper-Alloy Filler Metal (C. E. Swift, chairman) held two meetings during the past year. At the first meeting, the specifications to be written were discussed in a general way, the grouping of the copper alloys was agreed upon, and methods of test were tentatively fixed. It was thought that the composition of the alloys could best be determined by tests on core wire of the electrodes, though it was admitted that tests of weld metal would be more feasible, if the welding procedures for the test pads could be specified accurately enough to overcome variations in composition that might result from irregularities in the welding procedure. The lengths of electrodes and location of the grip were discussed without reaching any definite decision. This meeting was adjourned with the recommendation that Proposed Tentative Specifications for Copper and Copper-Alloy Arc-Welding Electrodes be prepared and submitted to the members of the committee for comment.

At the second meeting a draft of a portion of the specifications was considered. The various sections of this draft were discussed and the decisions agreed upon were reported to the members of the subcommittee with a request for comments on the work accomplished and suggestions for completing the table of chemical requirements. Thus far comments and suggestions have been received from several members of the subcommittee.

Subcommittee VII on Hard Facing Filler Metal (M. G. Sedam, chairman) was organized, in line with action taken at the June, 1944, meeting of the joint committee, superseding the previous Subcommittee VII on Electrode Chart. Selection of the personnel of the subcommittee has been completed, and the subcommittee will undertake its assigned work in the near future.

This report has been submitted to letter ballot of the committee which consists of 70 members; 54 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. H. DEPPELER,
Chairman.

S. A. GREENBERG,
Secretary.

REPORT OF COMMITTEE B-1

ON

COPPER AND COPPER-ALLOY WIRES FOR ELECTRICAL CONDUCTORS*

Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors held two meetings during the year. Both of these meetings were held in New York, N. Y., on November 20, 1944, and on March 16, 1945.

The present membership of Committee B-1 is 48, of whom 23 are classified as producers, 16 as consumers, and 9 as general interest members.

Subsequent to the 1944 Annual Meeting, Committee B-1 presented to the Society through Committee E-10 on Standards a proposed Tentative Method of Test for Resistivity of Copper and Copper-Alloy Electrical Conductors. This recommendation was accepted[1] by Committee E-10 on August 28, 1944, and the new tentative method appears in the 1944 Book of A.S.T.M. Standards, Part I, bearing the designation B 193 – 44 T. On the same date, the Standards Committee approved the withdrawal of the Emergency Specifications for Lead-Coated and Lead-Alloy-Coated Copper Wire for Electrical Purposes (ES – 1a) and Emergency Alternate Provision EA – B 8 in line with the actions set forth in the 1944 report.

I. REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revision in three standard specifications, as set forth below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Specifications for Tinned Soft or Annealed Copper Wire for Electrical Purposes, (**B 33 – 39**):[2]

Table I.—Delete from this table the tensile strength requirements for sizes 0.0201 in. and smaller. This change will take cognizance of the practical difficulties of determining areas with adequate precision to make the tensile requirement valid and recognizes the elongation test as determinative for very fine wire.

Section 6.—Add a new Paragraph (*a*) to read as follows, relettering the present Paragraph as (*b*). The practice stated in this new paragraph has been considered general in the industry, but recent interpretations indicate the desirability of a definite statement with respect thereto.

> 6. (*a*) The continuity of coating on the wire shall be determined on representative samples taken before stranding or insulating.

Section 10.—Change from its present form: namely,

> 10. A mechanical test for adhesion of tinning may be made by bending the wire around a rod having a diameter equal to four times the diameter of the wire, and dipping the bent portion of the wire only in the sodium polysulfide solution (Section 8 (*b*)), for 30 sec. Any cracking or parting of the coating shown by blackening of the copper shall be cause for rejection.

to read as follows:

> 10. (*a*) *Length of Specimen.*—Test specimens shall be approximately 12 in. in length and shall

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting these recommendations to Committee E-10 on Standards, Committee B-1 reported the following results of the letter ballot vote from a committee membership of 46, 36 members returned their ballots, 30 of whom voted affirmatively, 1 negatively, and 5 members marked their ballots "not voting."

[2] 1944 Book of A.S.T.M. Standards, Part I.

be tagged or marked to correspond with the coil, spool, or reel from which they are cut.

(*b*) *Preparation of Specimen.*—The specimens shall be thoroughly cleaned if required by immersion in benzine, ether, distilled petroleum ether, or carbon tetrachloride for at least 3 min., then removed and dried. The specimens thus cleaned shall be kept wrapped in a clean dry cloth until tested. That part of the specimens to be immersed in the test solution shall not be handled. Care shall be taken to avoid abrasion of the surface to be subjected to test. Wire of sizes 0.005 in. and smaller may be cleaned after wrapping around the mandrel.

(*c*) *Wrapping Procedure.*—The test specimen shall be slowly wrapped in a suitable manner in an open helix around a polished mandrel having rounded ends and a diameter equal to four times the diameter of the specimen. Care shall be taken not to stretch the specimen during the wrapping operation. The spacing of the consecutive turns shall be approximately equal to the diameter of the wire. For sizes 0.021 in. and smaller not more than six helical turns shall be used for the test, and for wire larger than 0.021 in. not more than three turns shall be used.

(*d*) *Immersion Test.*—The helically wrapped portion of the test specimen shall be removed from the mandrel and completely immersed in the sodium polysulfide solution (Section 8(*b*)) for 30 sec. at the temperature prescribed in Section 9(*a*). On removal from the sodium polysulfide solution, the specimen shall be rinsed immediately in clean water and the excess removed by shaking.

(*e*) *Examination of Specimen.*—The outer peripheral surface of the helically wrapped portion of the specimen shall be visually examined. For wires 0.021 in. and smaller, a magnification not greater than three times may be used. Any cracking or parting of the coating in this area shown by blackening of the copper shall be cause for rejection. A grayish appearance of the coating after immersion shall not constitute failure.

(*f*) *Retest.*—In the event of failure, two additional specimens shall be tested. If either of these specimens fails, the coil, reel, or spool shall be rejected.

Standard Specifications for Soft or Annealed Copper Wire (**B 3 – 41**):[2]

Table I.—Make the same change in this table as recommended above in Table I of Standard Specifications B 33.

Standard Specifications for Soft Rectangular and Square Copper Wire for Electrical Conductors (**B 48 – 42**):[2]

Title.—Add the word "bare" between "square" and "copper."

Section 1.—In Paragraph (*a*) add the word "bare" between "annealed" and "copper."

In Paragraph (*b*) add the following sentence to the description of Type B: "Type B wire of thickness less than 0.0201 in. or with a ratio of width to thickness greater than 30 to 1 is not contemplated in these specifications."

Section 5 (*a*).—Change from its present form: namely,

> 5. (*a*) Type B wire shall successfully withstand being bent edgewise through 180 deg. around a mandrel of the diameter prescribed in Table I without cracking on the outside of the bent portion. Intermediate thicknesses or widths shall conform to the requirements for the next larger size.

to read as follows:

> 5. (*a*) Type B wire shall successfully withstand bending edgewise through 180 deg. around a mandrel without cracking. The mandrel diameter expressed in increments of $\frac{1}{32}$ in. shall be equal to one half the nominal width of the material being bent. When this diameter falls within an increment of $\frac{1}{32}$ in., the next smaller $\frac{1}{32}$-in. increment shall be used as the mandrel diameter. In no case shall the mandrel diameter be less than $\frac{5}{32}$ in. In no case shall this bending test be applied to wire of thickness less than 0.0201 in. or with a ratio of width to thickness greater than 30 to 1.

Table I.—Omit this table which shows mandrel diameters for bending tests.

Section 6.—Change the last sentence to read as follows by the addition of the italicized figures and the omission of those in brackets: "At a temperature of 20 C. (68 F.) the resistivity shall not exceed [891.58] *875.20* ohms (mile, pound)."

Section 7.—In Paragraph (*a*) add a reference to Notes 7 and 8.

Change Paragraph (*d*) from its present form to read as follows, retaining the present Fig. 1:

(*d*) The corners of the wire shall be rounded within the limits of radii 25 per cent under and 25 per cent over (as determined by a radius gage) of those values specified in Table I.

TABLE I.—RADII IN INCHES OF CORNERS OF SQUARE AND RECTANGULAR WIRE.

Specified Thickness, in.	Specified Width, in.		
	0.751 and over	0.189 to 0.750, incl.	Up to 0.188, incl.
0.689 and over	$\frac{3}{16}$	$\frac{3}{16}$	...
0.688 to 0.439, incl.	$\frac{1}{8}$	$\frac{3}{32}$	...
0.438 to 0.226, incl.	$\frac{3}{32}$	$\frac{1}{16}$	...
0.225 to 0.166, incl.	$\frac{1}{16}$	$\frac{3}{64}$	$\frac{3}{64}$
0.165 to 0.126, incl.	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$
0.125 to 0.073, incl.	rounded edge[b]	$\frac{1}{32}$	$\frac{1}{64}$
0.072[a] to 0.051, incl.	rounded edge[b]	rounded edge[b]	$\frac{1}{64}$
0.050 and under	rounded edge[b]	rounded edge[b]	rounded edge[b]

[a] Square wire 0.072 in. and under shall have a corner radius of 0.012 in. ± 25 per cent.

[b] A rounded edge is an edge produced by rolling round wire to the size specified either with or without edging rolls (see Fig. 1).

Fig. 1.—Change the title of this figure from its present form to read as follows: "Sections of Wires with Rounded Edges and Rounded Corners."

TABLE II.—AREAS OF SQUARE COPPER WIRE.

Size, in.[a]	Area of Perfect Square		Corner Radius, in.	Calculated Departure,[b] sq. mils	Theoretical Net Area, sq. mils
	sq. in.	sq. mils			
0.0508	0.002583	2583	0.012	124	2459
0.0570	0.003257	3257	0.012	124	3133
0.0640	0.004107	4107	0.012	124	3983
0.0719	0.005178	5178	0.012	124	5054
0.0808	0.006530	6530	0.016	209	6321
0.0907	0.008234	8234	0.016	209	8025
0.1019	0.010380	10380	0.016	209	10171
0.1144	0.013090	13090	0.016	209	12881
0.1285	0.016510	16510	0.032	838	15672
0.1443	0.020820	20820	0.032	838	19982
0.1620	0.026250	26250	0.032	838	25412
0.1819	0.033100	33100	0.047	1887	31213
0.2043	0.041740	41740	0.047	1887	39853
0.2294	0.052640	52640	0.063	3353	49287
0.2576	0.066370	66370	0.063	3353	63017
0.2893	0.083690	83690	0.063	3353	80337
0.3249	0.105500	105500	0.063	3353	102147
0.3648	0.133100	133100	0.063	3353	129747
0.4096	0.167800	167800	0.063	3353	164447
0.4600	0.211600	211600	0.094	7545	204055

[a] While four significant figures are given, only three are used in most practical measurements.

[b] The reduction in area due to the rounding of the corners.

Explanatory Notes.—In Note 3 delete the second column of resistivity values.

Add new Notes 7 and 8 to read as follows:

NOTE 7.—Table II gives the net area in square mils for square wires in sizes 0.051 to 0.460 in., inclusive, allowance having been made for the reduction in the area occasioned by the rounding of the four corners of the wire to the dimensions shown in Table I of these specifications. The areas are for those dimensions specified and do not take into account probable increase or decrease in area due to tolerances. This information is intended for use in calculations and for such other purposes as may be agreed upon by the manufacturer and the purchaser.

NOTE 8.—Table III gives the net area in square mils to be deducted from circumscribing rectangles of rectangular wire cross-sections to obtain the net cross-sections in square mils of the finished wire. The reduction in square mils is based on rounding of the four corners of the wire in accordance with the radii shown in Table I of these specifications. The areas to be deducted are based on the radii specified and do not take into account probable increase or decrease in area due to tolerances. This information is intended for use in calculations and for such other purposes as may be agreed upon by the manufacturer and the purchaser.

TABLE III.—REDUCTION OF AREA IN SQUARE MILS FROM CIRCUMSCRIBING RECTANGLES DUE TO ROUNDING OF CORNERS OF RECTANGULAR WIRE.

Specified Thickness, in.	Specified Width, in.		
	0.751 and over	0.189 to 0.750, incl.	0.188 and under
0.689 and over	30178	30178	....
0.688 to 0.439, incl.	13413	7545	....
0.438 to 0.226, incl.	7545	3353	....
0.225 to 0.166, incl.	3353	1887	1887
0.165 to 0.126, incl.	3353	838	838
0.125 to 0.073, incl.	[a]	838	209
0.072 to 0.051, incl.	[a]	[a]	209
0.050 and under	[a]	[a]	[a]

[a] For wire with rounded edges, the calculated reduction of area in square mils is equivalent to 214,600 T^2, where T is the thickness of the wire, in inches. For square wire, see Table II.

II. REVISION OF TENTATIVE SPECIFICATIONS

The committee recommends revision of five tentative specifications and methods and their continuation as tentative:

Tentative Specifications for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (**B 172 – 42 T**):[2,3]

Section 3(*c*).—Change the last sentence to read as follows by the addition of the

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[3] See Editorial Note, p. 101.

italicized words and the omission of those in brackets: "The tensile strength and elongation requirements for wires tested after removal from such annealed conductors shall not exceed the maximum tensile strength prescribed in Standard Specifications B 3 increased by 5 per cent, nor the minimum elongation prescribed therein reduced in numerical value by 5 per cent (for example, from [30] *20* per cent to [25] *15* per cent)."

Table I.—Add the following to footnote "*a*": "The constructions shown in this table provide for a finished, noncovered, stranded conductor approximately of the area indicated. When specified by the purchaser, usually to provide additional area to compensate for draw-down during subsequent processing, the number or size of wires composing the noncovered conductor may be increased as required."

Section 7 (a).—Change the second sentence to read as follows by the addition of the italicized figures and the omission of those in brackets: "In the latter case the maximum tensile strength permitted shall be increased 5 per cent and the minimum elongation permitted shall be reduced in numerical value 5 per cent (for example, from [30] *20* per cent to [25] *15* per cent)."

Section 10.—Change Paragraphs (*a*) and (*b*) to read as follows and add the the following new Paragraph (*c*):

10. (*a*) The calculated area of cross-section of a stranded conductor shall be considered to be the sum of the cross-sectional areas of its component wires—when measured perpendicularly to their axes.

(*b*) The cross-sectional area of a conductor designated as an A.w.g. size shall be not less than 98 per cent of the area indicated in column 1 of Table I for sizes 211,600 cm. and smaller. The cross-sectional area of a completed conductor not designated as an A.w.g. size shall be not less than 98 per cent of a calculated value obtained as the sum of the nominal cross-sectional areas of the individual wires.

(*c*) The method of determination of the area of cross-section shall be in accordance with commercial practice unless a particular method has been agreed upon by the manufacturer and the purchaser.

Tentative Specifications for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members for Electrical Conductors (**B 173 – 42 T**):[2, 3]

Section 3(c).—Make the same change in this section as recommended above in Section 3 (*c*) of Specifications B 172.

Table I.—Add the following to footnote "*a*": "The constructions shown in this table provide for a finished, noncovered, stranded conductor approximately of the area indicated. When specified by the purchaser, usually to provide additional area to compensate for draw-down during subsequent processing, the sizes of the wires composing the noncovered conductor may be increased as required."

Section 7 (a).—Make the same change in this section as recommended above in Section 7 (*a*) of Specifications B 172.

Section 10.—Make the same change in this section as recommended above in Section 10 of Specifications B 172.

Tentative Specifications for Bunch-Stranded Copper Conductors for Electrical Conductors (**B 174 – 42 T**):[2, 3]

Section 3(c).—Make the same change in this section as recommended above in Section 3 (*c*) of Specifications B 172.

Section 5.—Add new Paragraphs (*d*) and (*e*) to read as follows:

(*d*) Conductors of an intermediate nominal area in circular mils shall conform to requirements for lay of the next smaller conductor.

(*e*) Unless otherwise specified by the purchaser, bare or coated, bunch-stranded conductors shall be furnished under the requirements for maximum length of lay for ordinary flexing service, without separator.

NOTE.—Flexible cords, known commercially as types S, SJ, POSJ, and SV are considered to be for severe flexing service.

Table II.—Change from its present form to read as shown in the accompanying Table IV.

TABLE IV.—MAXIMUM LENGTH OF LAY FOR BUNCH-STRANDED CONDUCTORS.

Size A.w.g.	Nominal Diameter, in.	Nominal Area, cir. mils	Maximum Length of Lay, in.		
			For Ordinary Flexing Service		For Severe Flexing Service With or Without Separator
			Without Separator	With Separator	
7	0.167	20 820	3.00	3.00	3.00
8	0.149	16 510	2.75	2.75	2.75
9	0.133	13 090	2.50	2.50	2.50
10	0.118	10 380	2.25	2.25	2.25
12	0.093	6 530	1.75	2.0	1.6
14	0.074	4 107	1.50	2.0	1.375
16	0.059	2 583	1.375	2.0	1.00
18	0.047	1 624	1.25	2.0	0.8
20	0.037	1 022	1.00	2.0	

Section 6.—Letter the present paragraph as (*a*) and add a new Paragraph (*b*) to read as follows: "(*b*) If a separator is required to be furnished with the conductor, it shall be specified by the purchaser as to requirements for the kind and thickness of material and its application details."

Table III.—In the column headings change "Nominal Number of Wires" to read "Minimum Number of Wires."

Add to the table caption reference letter "*a*" and add the following reference note beneath the table:

> [a] This table shows a variety of strand constructions useful and generally adequate to meet the needs encountered. It is not intended that the constructions listed in this table be exclusive of other constructions that may appear desirable in certain applications employing the same number of wires. The constructions shown in this table provide for a finished, noncovered, stranded conductor approximately of the area indicated. When specified by the purchaser, usually to provide additional area to compensate for draw-down during subsequent processing, the number or size of wires composing the noncovered conductor may be increased as required.

Section 7 (a).—Make the same change in this section as recommended above in Section 7 (*a*) of Specifications B 172.

Section 10.—Make the same change in this section as recommended above in Section 10 of Specifications B 172, except that in Section 10 (*b*) the first sentence shall read as follows: "The cross-sectional area of a conductor designated as an A.w.g. size shall be not less than 98 per cent of the area indicated in Column 1 of Table III."

Tentative Specifications for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes (**B 189 - 44 T**):[2]

Section 6.—Add a new Paragraph (*a*) to read as follows and letter the present paragraph as (*b*): "6. (*a*) The continuity of coating on the wire shall be determined on representative samples taken before stranding or insulating."

The recommendations in this report have been submitted to letter ballot of the committee which consists of 48 members, with the result shown in Table V.

TABLE V.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Spec. for Tinned Soft or Annealed Copper Wire for Electrical Purposes (B 33 - 39)	43	0	2
Spec. for Soft or Annealed Copper Wire (B 3 - 41)	34	0	8
Spec. for Soft Rectangular and Square Copper Wire for Electrical Conductors (B 48 - 42)	34	0	11
II. REVISION OF TENTATIVES			
Spec. for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (B 172 - 42 T)	38	2	6
Spec. for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors (B 173 - 42 T)	36	2	8
Spec. for Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 - 42 T)	37	1	8
Spec. for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes (B 189 - 44 T)	32	0	9

FUTURE WORK OF THE COMMITTEE

Information is to be collected and study made with respect to suitable equipment for making bending tests on flat wire made in accordance with Standard Specifications for Soft Rectangular and Square Copper Wire for Electrical Conductors (B 48 – 42).

A subject group has been appointed to study a discrepancy in Table II, Note "a," of the Standard Specifications for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (B 8 – 44) in regard to stranding.

The committee has in preparation a revision of the Tentative Method of Test for Resistivity of Copper and Copper-Alloy Electrical Conductors (B 193 – 44 T) involving a number of changes concerned largely with the nomenclature used in connection with this method but do not affect the substance of the test.[3]

Recommendations have been made to the Society by this committee in regard to changing the scope of the committee to include noncovered electrical conductors of materials other than copper, such as aluminum, magnesium, steel, and Copperweld. This change in scope, if authorized, will increase the work of the committee, will require augmentation of the membership, and will justify a fuller organization into subcommittees than has in the past seemed advisable.

This report has been submitted to letter ballot of the committee, which consists of 48 members; 40 members returned their ballots of whom 39 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

J. H. FOOTE,
Chairman.

E. H. KENDALL,
Acting Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 3, a number of recommendations affecting tentatives referred to in the report were submitted by Committee B-1 and accepted by the Administrative Committee on Standards on June 27, 1945. The revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Subsequent to the Annual Meeting, Committee B-1 presented to the Society through the Standards Committee the following recommendations:

Additional Revisions in Tentative Specifications for:

Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (B 172 – 45 T),
Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members for Electrical Conductors (B 173 – 45 T), and
Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 – 45 T).

These recommendations were accepted by the Standards Committee on October 23, 1945 and the latest revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I, under the designations indicated above.

On January 14, 1946 the Administrative Committee on Standards accepted the recommendation presented by Committee B-1 for revision of the Tentative Method of Test for Resistivity of Copper and Copper-Alloy Electrical Conductors (B 193 – 44 T). The method in its revised form appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE B-2

ON

NON-FERROUS METALS AND ALLOYS*

Committee B-2 on Non-Ferrous Metals and Alloys held one meeting, on June 29, 1944, in New York, N. Y., during the 1944 Annual Meeting of the Society.

Subsequent to the Annual Meeting Committee B-2 presented to the Society through Committee E-10 on Standards proposed revisions in the Tentative Specifications for Oxygen-Free Electrolytic Copper Wire Bars, Billets, and Cakes (B 170 – 43 T). This recommendation was accepted[1] by the Standards Committee on September 21, 1944, and the revised tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part I, under the designation B 170 – 44 T.

On October 24, 1944, the Standards Committee accepted revisions in Emergency Alternate Provisions EA – B 23a applying to the Standard Specifications for White Metal Bearing Alloys (Known Commercially as "Babbitt Metal") (B 23 – 26) and in Emergency Alternate Provisions EA – B 32a applying to the Tentative Specifications for Soft Solder Metal (B 32 – 40 T), as recommended by Committee B-2. The revised emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part I, under the designations EA – B 23b and EA – B 32b, respectively.

The Advisory Committee held a meeting in New York, N. Y., on December 11, 1944. Changes in membership were approved, the business before the subcommittees discussed, and by unanimous vote, jurisdiction over the Standard Specifications for Phosphor Copper (B 52 – 43)[2] and for Silicon Copper (B 53 – 43)[2] was transferred to Committee B-5 on Copper and Copper Alloys, Cast and Wrought. It was also unanimously voted that the Standard Specifications for Phosphor Tin (B 51 – 42)[2] be withdrawn since they cover a material no longer in general commercial use. In transferring jurisdiction of these three standards to Committee B-5, attention was called to this recommendation regarding Specifications B 51, and action is accordingly being taken by Committee B-5 on the withdrawal of the specifications for phosphor tin.

A suggestion had been made at the June meeting of the committee that tentative specifications for refined tin, antimony, and bismuth be prepared. The Advisory Committee unanimously agreed that at this time there is no apparent need for specifications for these metals.

Concerning the work of the committee, the Advisory Committee discussed possible organizational changes and decided, for the present and under the conditions caused by the war, to take no action.

The committee records with sorrow the death of Thomas A. Wright. Mr. Wright's death was as untimely as it was shocking. The committee had looked upon him as one of the juniors of this group of men. He had never spared his time nor energy in helping solve the problems the committee had to consider, so we had come to look upon his resources as inexhaustible. His priceless and unique contributions to these deliberations always were conditioned by his absolute intellectual honesty, his insistence that the spoken or printed word or figure mean exactly what it said, and that it should have the best possible basis in experimental fact. Beyond all this was his friendliness; each of us will feel the loss of that companionship with increasing frequency, and we therefore beg to offer the sympathy that is in our hearts.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting this recommendation to Committee E-10 on Standards, Committee B-2 reported results of the letter ballot vote as follows: Of a total membership of 134, 77 members returned their ballots, of whom 60 voted affirmatively, 0 negatively, and 17 members marked their ballots "not voting."

[2] 1944 Book of A.S.T.M. Standards, Part I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Refined Copper (J. L. Christie, chairman) prepared the revisions on Tentative Specifications B 170 mentioned above as well as editorial changes in the Standard Specifications for Fire-Refined Copper Other than Lake (B 72 – 33)[2] which have since been incorporated in the specifications.

The subcommittee met in New York, N. Y., on March 6, 1945, discussed the Emergency Specifications for Fire-Refined Copper for Wrought Products and Alloys (ES – 7),[2] and appointed a committee to draw up proposed tentative specifications for this type of fire-refined copper.

A list of commercially available coppers containing small amounts of added elements is being considered for presentation to the Society.

Subcommittee II on Refined Lead, Tin, Antimony, and Bismuth (T. A. Wright, chairman) presented to the Advisory Committee a suggestion that had been received that specifications for refined tin, antimony, and bismuth be prepared. As mentioned earlier in this report, the Advisory Committee decided that there is no apparent need for such specifications.

Subcommittee III on White Metal Alloys (G. H. Clamer, chairman) recommended the following editorial changes which, as mentioned in the 1944 Report, have since been incorporated in the Tentative Specifications for Soft Solder Metal (B 32 – 40 T):[2]

Section 1 (b) and Appendix.—Change the word "density" to read "specific gravity," and add the following three compositions to the Table of Properties of Soft Solder Metal:

Nominal Composition, per cent		
Tin	Lead	Antimony
35	65	...
35	63	2
15	84.5	0.5

This subcommittee is responsible also for the revisions in Emergency Alternate Provisions EA – B 23a and EA – B 32a applying to the Standard Specifications for White Metal Bearing Alloys (Known Commercially as "Babbit Metal") (B 23 – 26) and the Tentative Specifications for Soft Solder Metal (B 32 – 40 T), respectively, which as mentioned earlier in this report were accepted by the Society on October 24, 1944.

Subcommittee IV on Refined Zinc and Wrought Zinc (E. H. Bunce, chairman) held a meeting on June 29, 1944, in New York, N. Y., to consider the request of Committee B-6 on Die-Cast Metals and Alloys that the impurity limits in the Standard Specifications for Slab Zinc (Spelter) (B 6 – 37)[2] be lowered so that there would be a spread between the requirements for slab zinc and the requirements for zinc-alloy die castings.

At this meeting it was proposed to change the requirements for lead and cadmium to 0.006 and 0.004 max., per cent, respectively, and to add a footnote to read as follows: "Analysis shall not regularly be made for tin but when used for die castings, if found by the purchaser, tin shall not exceed 0.003 per cent. Greater amounts may constitute cause for rejection."

In the light of the negative viewpoint subsequently expressed by some members of the subcommittee on this recommendation, the chairman of Committee B-2 has recommitted the matter to Subcommittee IV with the recommendation that a meeting be held with representatives from Committee B-6 in an effort to agree upon requirements acceptable to all parties.

Subcommittee VII on Refined Nickel and High-Nickel Alloys, Cast and Wrought (O. B. J. Fraser, chairman) is giving preliminary consideration to the development of specifications for wire products in high-nickel alloys.

The chairman, with his own staff, has been giving consideration to any necessary revisions in the tentative specifications under the jurisdiction of the subcommittee. When the work has progressed sufficiently, recommendations will be submitted to the subcommittee.

This report has been submitted to letter ballot of the committee which consists of 115 members; 76 members returned their ballots, of whom 73 have voted afirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

E. E. THUM,
Chairman.

G. HOWARD LEFEVRE,
Secretary.

REPORT OF COMMITTEE B-3

ON

CORROSION OF NON-FERROUS METALS AND ALLOYS*

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys held a meeting in New York, N. Y., on June 28, 1944. A meeting of the Advisory Committee was held in New York, N. Y., on March 22, 1945, in place of the regular meeting of the committee, which was canceled when the Spring Group Committee Meetings of the Society were canceled.

The resignation of Vice-chairman R. W. Waring, due to change in employment, was accepted with regret at the March meeting of the Advisory Committee. The Advisory Committee elected C. H. Sample of the Bell Telephone Laboratories to serve as vice-chairman for the remainder of the term.

The committee consists of 98 members, of whom 73 are voting members; 35 are classed as producers, 27 as consumers, and 11 as general interest members.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Total Immersion (A. W. Tracy, chairman).—This subcommittee is studying the Recommended Practice for Plant Corrosion Tests (A 224 – 41) in order to propose changes making it applicable to the testing of non-ferrous metals and alloys. Another project planned by the subcommittee is a series of cooperative tests among several laboratories to determine if reasonably reproducible results can be obtained using the Tentative Method of Total Immersion Corrosion Test of Non-Ferrous Metals (B 185 – 43 T). In accordance with action taken at the meeting of the Advisory Committee, it is recommended that Tentative Method B 185 be continued as tentative without revision.

Subcommittee II on Alternate Immersion Test (H. L. Burghoff, chairman).—The Tentative Method of Alternate Immersion Corrosion Test of Non-Ferrous Metals (B 192 – 44 T) has been published in the 1944 Book of A.S.T.M. Standards, Part I. The subcommittee will welcome comments or suggestions for revision of this tentative method.

Subcommittee III on Spray Test (C. E. Heussner, chairman).—The revised Tentative Method of Salt Spray (Fog) Testing (B 117 – 44 T) completed last year by this subcommittee is also published in the 1944 Book of A.S.T.M. Standards, Part I.

A subgroup cooperating with Committee B-8 on Electrodeposited Metallic Coatings has been formed to study the important factors of salt spray tests. Members of this group are: K. Gustav Soderberg, chairman; V. M. Darsey; L. J. Waldron (special adviser member); C. H. Sample; N. E. Promisel (special adviser member); Charles Davidoff (representing Committee B-8); C. J. Walton (representing E. H. Dix, Jr.); and D. M. Overcash.

This group met on February 8, 1945, in Washington, D. C., and a tentative program for study of the effect of settling of fog on the rate of corrosion of selected

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[*] Presented at Forty-Eighth Annual Meeting of the Society June 27, 1945.

materials was reviewed and accepted. This program of tests will proceed as rapidly as possible.

Subcommittee V on Statistical Analysis and Planning of Corrosion Testing (W. E. Campbell, chairman).—This subcommittee has been inactive, but the chairman has aided Subcommittee VI on Atmospheric Corrosion in connection with statistical calculations on the ten-year tests. A tentative project before the subcommittee is the preparation of suggested methods for planning corrosion tests, so that resultant data could be treated statistically.

Subcommittee VI on Atmospheric Corrosion (W. H. Finkeldey, chairman).—The atmospheric exposure tests on 24 non-ferrous metals and alloys are being continued in accordance with the general test program of the subcommittee. A final and complete report of the results of tests made on samples removed from the racks in 1943, has been prepared and appears in corrected form in the 1944 *Proceedings* of the Society.

The subcommittee has given consideration to further atmospheric exposure tests on non-ferrous metals and alloys developed since the test program was started, principally aluminum and magnesium alloys.

Subcommittee VII on Weather (F. L. LaQue, chairman).—No investigation of weather factors will be started until after the war. In line with a suggestion made at a meeting of the Advisory Committee on Corrosion, representatives from Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys have been appointed to serve on this subcommittee.

Subcommittee VIII on Galvanic and Electrolytic Corrosion (L. J. Gorman, chairman).—The joint working committee on galvanic corrosion of magnesium alloys, comprised of representatives of this subcommittee and of Subcommittee IV of Committee B-7 on Light Metals and Alloys, has about completed its plans for galvanic corrosion tests on atmospheric exposure of two magnesium alloys, namely, type AZ31X (old A.S.T.M. designation No. 18X) and type M1 (old A.S.T.M. designation No. 11). These alloys are to be tested in combination with the following metals and alloys:

Mild steel (0.05 to 0.08 Cu),
70-30 Brass, ½ Hard,
24ST Aluminum alloy,
75ST Aluminum alloy,
52S or 56S Aluminum alloy,
2S Aluminum alloy,
Stainless steel, type 304,
Monel metal,
Nickel,
Zinc,
Cadmium-plated steel (0.0005 in. coating), and
Zinc-plated steel (0.0005 in. coating).

The magnesium alloy AZ31X will be tested with the complete list of other metals, while the type M1 alloy will be tested with a limited number of the other metals, as follows:

70-30 Brass,
52S or 56S Aluminum alloy,
2S Aluminum alloy, and
Zinc.

The test couples will be placed on atmospheric exposure at the following test locations:

1. A.S.T.M. test rack at 463 West St., New York, N. Y.,
2. A.S.T.M. test rack at State College, Pa.,
3. International Nickel Co. Test Rack, Kure Beach, N. C., and
4. A humid tropical location to be selected remote from sea coast influence.

Three types of galvanic couples have been selected for the test as follows:

1. The disk-type couple similar to that used for the stainless steel tests now on exposure,
2. A spool-type couple which consists of wire of one test material wound on a threaded spool of another test material. This couple is similar to the type used by the Bell Telephone Laboratories, and

3. A plate-type couple which consists of a plate of the magnesium alloy across which are bolted strips of the various other metals. These plates are so designed that standard A.S.T.M. tension test specimens can be cut from the plate at the end of the test.

In the first two types of couple the amount of corrosion will be evaluated by inspection and by the loss of weight in the test specimen. In the plate-type couple it is proposed to obtain quantitative information on the amount of corrosion through the measurement of tensile strength.

The test program as a whole is now sufficiently advanced so that the working committee can proceed with the procurement of the required test specimens and the assembly of the couples.

This report has been submitted to letter ballot of the committee which consists of 73 voting members; 68 members returned their ballots of whom 67 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

H. S. RAWDON,
Chairman.

A. W. TRACY,
Secretary.

REPORT OF COMMITTEE B-4

ON

ELECTRICAL-HEATING, ELECTRICAL-RESISTANCE, AND ELECTRIC-FURNACE ALLOYS*

Committee B-4 on Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys held three meetings during the year in New York, N. Y., on June 27, 1944, October 5, 1944, and February 8 and 9, 1945.

The committee consists of 58 members, of whom 28 are classified as producers, 23 as consumers, and 7 as general interest members.

The first annual supplement to the Bibliography and Abstracts on Electrical Contacts, prepared by Subcommittee X on Contact Materials, has been published in 1945. It consists of 32 pages on electrical contacts and circuit interruption, and contact materials, containing 153 references, 84 new and revised references prior to 1943, and 69 new references to articles in 1943–1945. The book published in 1944 has been found to be a very useful reference and a large number of copies has been sold.

I. Revisions of Standards, Immediate Adoption

The committee recommends for immediate adoption revisions in the Standard Method of Test for Temperature-Resistance Constants of Alloy Wires for Precision Resistors (B 84 – 36) and in the Standard Method of Test for Temperature-Resistance Constants of Sheet Materials for Shunts and Precision Resistors (B 114 – 39) comprising the addition of the following paragraph to Section 7 of B 84 and to Section 6 of B 114:

> In an automatically controlled bath, the temperature of the bath at any time during the test at any temperature level shall not differ from its mean temperature by more than 0.2 C. In a manually controlled bath, the rate of change of temperature shall not exceed 0.2 C. per min.

These recommendations have been submitted to letter ballot of the committee which consists of 58 members; on B 84, 40 members returned their ballots, of whom 32 have voted affirmatively, 0 negatively, and 8 members marked their ballots "not voting"; on B 114, 40 members returned their ballots, of whom 31 have voted affirmatively, 0 negatively, and 9 members marked their ballots "not voting."

II. Editorial Changes in Standards

The committee also recommends editorial changes in two standard methods as follows:

In the Standard Method of Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (B 70–39) make the following change in Section 5 (*b*): In the third line substitute "power lost in" for "energy liberated." Also in the last sentence replace "energy" by "power" and under the formula add "W = power loss in watts."

In the Standard Method of Test for Thermoelectric Power of Electrical-Resistance Alloys (B 77 – 33) change Sections 6 (*a*), (*b*), and (*c*) to read as follows:

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

6. (*a*) The method in which a potentiometer is used to compare the unknown emf. with that of a standard cell.

(*b*) The method in which the unknown emf. is equated to the difference of potential between the terminals of a standard resistor when a measured current flows through it.

(*c*) The method in which the emf. is measured by the deflection of a suitable measuring instrument.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Electrical Tests (P. H. Dike, chairman).—The subcommittee is reviewing the A.S.T.M. methods of making electrical tests on electrical-resistance and electrical-heating alloys, prepared by the committee and issued some years ago, in order to make any necessary changes to bring them up to date.

Subcommittee V on Wrought and Cast Alloys for High-Temperature Use (J. W. Harsch, chairman).—In 1944 Tentative Specifications for Chromium-Nickel-Iron Alloy Castings (25-12 Class) for High-Temperature Service (B 190 – 44 T), prepared by the subcommittee, were issued under the joint sponsorship of Committee B-4 and Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. An appendix listing the more important technical papers on creep at elevated temperatures is being prepared. Further work is being done to explore the relationship of magnetic permeability to creep for this alloy.

Specifications for Chromium-Nickel-Iron Alloy Castings (35 per cent Nickel, 15 per cent Chromium, Balance Iron) for High-Temperature Service are in course of preparation.

Subcommittee VII on Thermostat Metals (P. H. Brace, chairman).—The subcommittee is working on the development of drawings for suitable testing equipment to be used in the Tentative Method of Test for Equivalent Yield Stress of Thermostat Metals at Elevated Temperatures (B 191 – 44 T). The helix type of specimen has been selected as the most suitable for this application. This method of test is under consideration also to determine the elastic properties of spring materials at elevated temperatures.

Subcommittee VIII on Metallic Materials for Radio Tubes and Incandescent Lamps (S. A. Standing, chairman).—A number of methods for the determination of particle size has been studied by comparative tests in four laboratories on samples of several materials. The tests have been made and the results are being analyzed to determine the best procedure.

Further work has been done investigating methods of examining tungsten wire for cracks or other defects which would interfere with the sealing of tubes in which it is used. Several methods are under consideration.[1]

On account of the difficulty of accurately measuring the diameter of fine wires, a new method has been prepared in which a 200-mm. length of wire is weighed and the diameter calculated. It is intended to apply to wires of 0.002 in. in diameter or less. A draft of the method has been submitted to the subcommittee for review.[1]

A method for determining the strength of welds in wires used for leads is under consideration.[1]

At the request of the radio tube industry, the subcommittee is making a study of the emissivity of nickel cathodes to determine the effect of impurities and structure, and to develop the necessary methods of test for the control of this material. Authorization has been received for the committee to undertake the work, including chemical analysis and spectrographic analysis, with the aid of liaison representatives from Committee E-2 on Spectrographic Analysis and Committee E-3 on Chemical Analysis of Metals. Four sections have been formed—Metallurgical, Chemical, Presentation of Data on Production Tests, and Standardization of the Diode Test.

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[1] See Editorial Note, p. 110.

Subcommittee IX on Methods of Test for Alloys in Controlled Atmospheres (P. H. Brace, chairman).—No further work has been done during the year. Tests to determine the effect of sulfur will be resumed as soon as the War Program will permit.

Subcommittee X on Contact Materials (F. E. Carter, chairman).—The testing machine described in the Tentative Method for Life Test of Electrical Contact Materials (B 182 - 43 T) has been studied during the year and numerous tests made. Minor adjustments have been made in the device for operating the contacts, so as to provide consistent results, especially as regards the number of welds per 100,000 cycles. The same changes will be made in all of the machines which have been built. Then further tests will be made and other materials will be tested.

A study is being made of various properties of contact materials which may affect the load-carrying capacity of contacts. Thus far this has been limited to hardness tests, using the Rockwell, Rockwell Superficial, and Vickers machines. A proposed tentative method is being prepared.

During the year, agreement has been reached on standard dimensions for projection welding contacts and the dimensions and tolerances were published in the ASTM BULLETIN.[2] These were prepared in Section C on Standardization of Contact Forms and Sizes (A. B. Gibson, chairman) composed of representatives from the principal manufacturers and users of electrical contacts in cooperation with the National Electrical Manufacturers Assn. This follows the standardization of contact rivets in 1942. Work is under way on standard dimensions for contact screws and studs.

As mentioned earlier in this report, this subcommittee prepared the 1945 supplement to the Bibliography on Electrical Contacts which has just been completed.

This report has been submitted to letter ballot of the committee which consists of 58 members; 40 members returned their ballots, all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

DEAN HARVEY,
Chairman.

F. E. BASH,
Secretary.

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[2] ASTM BULLETIN, No. 131, December, 1944, p. 37.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-4 presented to the Administrative Committee on Standards the following recommendations:

New Tentative Method for:
Determination of Wire Diameter by Weighing (B 205 - 45 T),
Testing the Strength of Welded Joints of Lead Wires for Electronic Devices and Lamps (B 203 - 45 T), and
Testing Surface Flaws in Tungsten Seal Rod and Wire (B 204 - 45 T),
Revision of Tentative Method for:
Testing the Density of Fine Wire and Ribbon for Electronic Devices (B 180 - 43 T),
Testing Wire for Supports Used in Electronic Devices and Lamps (B 157 - 41 T), and
Testing Temper of Strip and Sheet Metals for Electronic Devices (B 155 - 41 T).
Revision of Tentative Specifications for:
Round Nickel Wire for Lamps and Electronic Devices (B 175 - 42 T), and
Chromium-Nickel-Iron Alloy Castings (25-12 Class) for High-Temperature Service (B 190 - 44 T).

These recommendations were accepted by the Standards Committee on January 16, 1946, and the new and revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE B-5

ON

COPPER AND COPPER ALLOYS, CAST AND WROUGHT*

Committee B-5 on Copper and Copper Alloys, Cast and Wrought, held one meeting during the year in New York, N. Y., on March 14, 1945. At this time, the Advisory Committee and Subcommittees A-1, A-2, A-3, A-4, B-1, and C-1 also met.

During the year 20 members were added to the committee and there were 17 removals.

C. H. Davis, secretary of the committee from 1937 to 1944, died on May 22, 1945. The committee will feel greatly the loss of his valued contributions to its activities.

At the present time, the committee consists of 120 members, of whom 105 are voting members; 47 are classified as producers, 45 as consumers, and 13 as general interest members.

RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS

Subsequent to the 1944 Annual Meeting, Committee B-5 presented to the Society, through Committee E-10 on Standards, the following recommendations:

Revised Emergency Alternate Provisions in Specifications for:

Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (EA – B 22b),
Composition Brass or Ounce Metal Castings (EA – B 62b),
Tin-Bronze and Leaded Tin-Bronze Sand Castings (EA – B 143b),
High-Leaded Tin-Bronze Sand Castings (EA – B 144b),
Leaded Red Brass and Leaded Semi-Red Brass Sand Castings (EA – B 145b), and
Leaded Yellow Brass Sand Castings for General Purposes (EA – B 146b).

Withdrawal of Emergency Alternate Provisions in Specifications for:

Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (EA – B 60a),
Rolled Copper-Alloy Bearing and Expansion Plates for Bridge and Other Structural Uses (EA – B 100),
Phosphor Bronze Sheet and Strip (EA – B 103),
Cartridge Brass Sheet, Strip, and Disk (EA – B 19),
Copper-Base Alloys in Ingot Form for Sand Castings (EA – B 30),
Brass Sheet and Strip (EA – B 36),
Leaded Brass Sheet and Strip (EA – B 121),
Copper-Base Alloy Forging Rods, Bars, and Shapes (EA – B 124),
Cartridge Brass Cartridge Case Cups (EA – B 129),
Gilding Metal Sheet and Strip (EA – B 130),
Gilding Metal Bullet Jacket Cups (EA – B 131)
Copper Rods, Bars, and Shapes (EA – B 133),
Brass Wire (EA – B 134),
Phosphor Bronze Rods, Bars, and Shapes (EA – B 139),
Copper-Nickel-Zinc Alloy Rod and Wire (EA – B 151),
Copper Sheet, Strip, and Plate (EA – B 152),
Phosphor Bronze Wire (EA – B 159), and
Aluminum Bronze Sheet and Strip (EA – B 169).

These recommendations were accepted by Committee E-10 on August 28, 1944, and the revised emergency provisions appear in ASTM BULLETIN, No. 130, October, 1944, pp. 10 and 11, and in the 1944 Book of A.S.T.M. Standards, Part I.

On November 22, 1944, the Standards Committee accepted the following recommendations of Committee B-5:

Revision of Tentative Specifications for:

Cartridge Brass Sheet, Strip, and Disks (B 19 – 44 T),

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

Brass Sheet and Strip (B 36 – 44 T),
Leaded Brass Sheet and Strip (B 121 – 44 T),
Gilding Metal Sheet and Strip (B 130 – 44 T),
Aluminum Bronze Sheet and Strip (B 169 – 44 T),

Copper Sheet, Strip, and Plate (B 152 – 44 T),
Naval Brass Rods, Bars, and Shapes (B 21 – 42 T),
Copper Rods, Bars, and Shapes (B 133 – 44 T),
Brass Wire (B 134 – 44 T),
Phosphor Bronze Rods, Bars, and Shapes (B 139 – 44 T),
Aluminum Bronze Rods, Bars, and Shapes (B 150 – 44 T),
Copper–Nickel-Zinc Alloy Rod and Wire (B 151 – 44 T),
Phosphor Bronze Wire (B 159 – 44 T),
Copper Bus Bars, Rods, and Shapes (B 187 – 44 T), and
Copper Bus Pipes and Tubes (B 188 – 44 T),

Tentative Revision of Standard Specifications for:

Manganese Bronze Rods, Bars, and Shapes (B 138 – 43), and
Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 43).

The revised tentative specifications and tentative revisions[1] appear in the 1944 Book of A.S.T.M. Standards, Part I.

Withdrawal of Emergency Alternate Provisions

Certain of the revisions being recommended in the standard and tentative specifications include changes now published as emergency alternate provisions. For the most part, these include references to the Emergency Specifications for Fire-Refined Copper for Wrought Products and Alloys (ES – 7). In a few other cases the emergency provisions are no longer necessary. The committee accordingly recommends that concurrently with the approval of the recommendations affecting standards in this report, the following emergency alternate provisions be withdrawn:

Emergency Alternate Provisions in Specifications for:

Copper Bars For Locomotive Staybolts (EA – B 12),
Copper And Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (EA – B 111),
Copper-Nickel-Zinc And Copper-Nickel Alloy Sheet and Strip (EA – B 122),
Miscellaneous Brass Tubes (EA – B 135),
Aluminum-Bronze Sand Castings (EA – B 148a), and
Copper-Alloy Condenser Tube Plates (EA – B 171).

Continuation of Emergency Alternate Provisions

The committee recommends that the following emergency alternate provisions be continued in their present form:

Emergency Alternate Provisions in Specifications for:

Free-Cutting Brass Rod for Use in Screw Machines (EA – B 16),
Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (EA – B 22b),
Steam or Valve Bronze Castings (EA – B 61),
Composition Brass or Ounce Metal Castings (EA – B 62b),
Tin-Bronze and Leaded Tin-Bronze Sand Castings (EA – B 143b),
High-Leaded Tin-Bronze Sand Castings (EA – B 144b),
Leaded Red Brass and Leaded Semi Red Brass Sand Castings (EA – B 145b), and
Leaded Yellow Brass Sand Castings For General Purposes (EA – B 146b).

Recommendations Affecting Standards

The committee is submitting five new tentative specifications, revisions in 18 tentative specifications, revisions in 11 standards for immediate adoption, the adoption of six tentatives and two tenta-

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[1] In submitting these recommendations to Committee E-10 on Standards, Committee B-5 reported the following results of the letter ballot vote from a committee membership of 103: B 19, affirmative 30, negative 0, ballots marked "not voting" 27; B 36, B 121, and B 152, affirmative 32, negative 0, ballots marked "not voting" 25; B 130, affirmative 31, negative 0, ballots marked "not voting" 26; B 169, affirmative 28, negative 0, ballots marked "not voting" 29; B 21, affirmative 32, negative 1, ballots marked "not voting" 23; B 133 and B 138, affirmative 29, negative 1, ballots marked "not voting" 26; B 134, affirmative 33, negative 0, ballots marked "not voting" 23; B 139, B 150, and B 151, affirmative 32, negative 1, ballots marked "not voting" 23; B 159, affirmative 32, negative 0, ballots marked "not voting" 24; B 187, affirmative 29, negative 0, ballots marked "not voting" 27; B 188, affirmative 30, negative 0, ballots marked "not voting" 26; B 140, affirmative 31, negative 1, ballots marked "not voting" 24.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE SPECIFICATIONS			
Spec. for Beryllium Copper Alloy Strip	33	1	36
Spec. for Beryllium Copper Alloy Strip, Special Grade	34	0	36
Spec. for Beryllium Copper Alloy Rod and Bar[a]	31	4	35
Spec. for Beryllium Copper Alloy Wire	34	0	36
Spec. for Copper-Silicon and Copper-Silicon-Zinc Alloy Castings	41	0	29
II. REVISIONS OF TENTATIVE SPECIFICATIONS			
Spec. for Naval Brass Rods, Bars, and Shapes (B 21 – 44 T)	43	0	27
Spec. for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 – 44 T)	36	0	34
Spec. for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 44 T)	43	0	27
Spec. for Seamless Copper Tubes (B 75 – 43 T)	38	0	32
Spec. for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 – 42 T)	39	0	31
Spec. for Copper Rods, Bars, and Shapes (B 133 – 44 T)	39	0	31
Spec. for Miscellaneous Brass Tubes (B 135 – 43 T)	42	0	28
Spec. for Phosphor Bronze Rods, Bars, and Shapes (B 139 – 44 T)	39	0	31
Spec. for High-Leaded Tin-Bronze Sand Castings (B 144 – 44 T)	42	0	28
Spec. for Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 – 44 T)	42	0	28
Spec. for Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 44 T)	40	0	30
Spec. for Aluminum-Bronze Sand Castings (B 148 – 44 T)	42	0	28
Spec. for Aluminum Bronze Rods, Bars, and Shapes (B 150 – 44 T)	38	0	32
Spec. for Copper-Nickel-Zinc Alloy Rod, Bar, and Wire (B 151 – 44 T)	37	0	33
Spec. for Copper Sheet, Strip, and Plate (B 152 – 44 T)	39	0	31
Spec. for Phosphor Bronze Wire (B 159 – 44 T)	39	0	31
Spec. for Copper Bus Bars, Rods, and Shapes (B 187 – 44 T)	38	0	32
Spec. for Copper Bus Pipes and Tubes (B 188 – 44 T)	38	1	31
III. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Spec. for Copper Bars for Locomotive Staybolts (B 12 – 42)	30	0	40
Spec. for Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 – 44)	42	0	28
Spec. for Copper Pipe, Standard Sizes (B 42 – 43)	39	0	31
Spec. for Brass Pipe, Standard Sizes (B 43 – 42)	40	0	30
Spec. for Seamless Copper Tubing, Bright Annealed (B 68 – 43)	40	0	30
Spec. for Copper Water Tube (B 88 – 41)	39	0	31
Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 44)	38	0	32
Spec. for Copper-Silicon Alloy Wire for General Purposes (B 99 – 42)	37	0	33
Spec. for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 43)	38	1	31
Spec. for Manganese Bronze Rods, Bars and Shapes (B 138 – 43)	41	0	29
Spec. for Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 43)	40	0	30
IV. ADOPTION OF TENTATIVES AS STANDARD			
Classification of Cast Copper-Base Alloys (B 119 – 40 T)	46	0	24
Spec. for Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 – 44 T)	40	0	30
Spec. for Brass Wire (B 134 – 44 T)	39	0	31
Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (B 153 – 41 T)	40	0	30
Method of Mercurous Nitrate Test for Copper and Copper Alloys (B 154 – 41 T)	49	0	21
Spec. for Copper-Alloy Condenser Tube Plates (B 171 – 42 T)	38	0	32
V. ADOPTION OF TENTATIVE REVISIONS OF STANDARDS			
Spec. for Manganese Bronze Rods, Bars, and Shape (B 138 – 43)	42	0	28
Spec. for Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 43)	40	0	30
VI. WITHDRAWAL OF STANDARDS			
Spec. for Phosphor Tin (B 51 – 42)	48	0	22
Spec. for Beryllium-Copper Alloy Rods, Bars, Sheet, Strip, and Wire (B 120 – 41 T)	40	0	30

TABLE I.—*Continued.*

[a] The classified vote on the new Tentative Specifications for Beryllium-Copper Alloy Rod and Bar was as follows: Affirmative: 12 producers, 16 consumers, 3 general interests; negative: 1 producer, 3 consumers.

tive revisions as standard, and the withdrawal of two specifications. The standards and tentatives affected are listed in Table I and the revisions recommended are given in detail in the Appendix.

The recommendations in this report have been submitted to letter ballot of the committee, which consists of 105 voting members, with the results shown in Table I.

ACTIVITIES OF THE ADVISORY COMMITTEE

Subsequent to the Annual Meeting, the Advisory Committee held two meetings primarily for the purpose of reorganizing the committee. The 13 old subcommittees were entirely reconstituted to form a new grouping of 8 subcommittees as follows:

Group A—Wrought Products:
- Subcommittee A-1, Plate, Sheet, and Strip
- Subcommittee A-2, Rods, Bars, and Shapes
- Subcommittee A-3, Wire and Wire Rod
- Subcommittee A-4, Pipe and Tube

Group B—Castings, and Ingots for Remelting:
- Subcommittee B-1, Castings, and Ingots for Remelting

Group C—Correlation:
- Subcommittee C-1, Methods of Test
- Subcommittee C-2, Tolerances
- Subcommittee C-3, Editorial and Publications

The by-laws of the committee were amended, principally to provide for the regrouping of the subcommittees and for the filing of nonvoting proxies with the secretary. The revised by-laws and re-organization of the committee and subcommittee structure have been approved by letter ballot and are published in the 1944 compilation of "A.S.T.M. Standards on Copper and Copper Alloys."

Subsequent to publication of the revised by-laws, the following revisions were approved by letter ballot:

Article II, Section 1.—Change the first sentence to read as follows by the addition of the italicized words:

> The scope of the committee shall be copper ingot for remelting, *deoxidizers and hardeners for copper alloys*, and commercial cast copper and wrought copper products directly intended for industrial use, including all alloys founded upon copper as a base material used in cast or wrought form.

Article VII, Section 5.—Renumber as Section 6 and add a new Section 5 to read as follows:

> Sec. 5. Official Committee B-5 representatives on other standing committees of the Society and on outside organizations shall report the results of important actions affecting Committee B-5. Such reports shall be submitted in writing to the secretary of Committee B-5 for presentation to the Advisory Committee at its next regular meeting for appropriate action.

On the recommendation of the Advisory Committee, Committee B-2 on Non-Ferrous Metals and Alloys transferred to Committee B-5, jurisdiction over the Standard Specifications for Phosphor Tin (B 51 – 42), the Standard Specifications for Phosphor Copper (B 52 – 43), and the Standard Specifications for Silicon Copper (B 53 – 43). These specifications have been assigned to Subcommittee B-1.

ACTIVITIES OF SUBCOMMITTEES

Following is a report on the activities of the several subcommittees during the year. The approved recommendations of the subcommittees affecting standards, are given earlier in this report or in the Appendix.

Subcommittee A-1 on Plate, Sheet, and Strip (R. A. Frye, chairman, R. A. Lubker, secretary) recommended that Emergency Alternate Provisions EA – B 122 and EA – B 171 applying to the Tentative Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 – 42 T) and for Copper-Alloy Condenser Tube Plates (B 171 – 42 T), be withdrawn and that the provisions be incorporated in the respective specifications. It was decided in revising Tentative Specifications B 122 to use the applicable tolerances of the Copper Brass Research Association. It was recommended that with slight revisions, Tentative Specifications B 171 be adopted as standard. Recommendations with respect to revision of the Tentative Specifications for Copper Sheet, Strip, and Plate (B 152

- 44 T) appear in the Appendix. The subcommittee prepared proposed new Tentative Specifications for Beryllium-Copper Alloy Strip[2] to replace a part of the Tentative Specifications for Beryllium-Copper Alloy Rods, Bars, Sheet, Strip, and Wire (B 120 - 41 T) as well as proposed new Tentative Specifications for Beryllium-Copper Alloy Strip, Special Grade.[2]

A special committee (G. R. Gohn, D. Basch, C. H. Davis, H. S. Freynik, T. C. Merriman, and G. Williams, Jr.) was appointed to study Specifications B 122 for the purpose of (*1*) considering the introduction of a new alloy, (*2*) recommending requirements for such a new alloy, and (*3*) revising the physical requirements of the specification.[3]

Subcommittee A-2 on Rods, Bars, and Shapes (H. C. Ashley, chairman) recommended that Emergency Alternate Provisions EA - B 12 applying to the Standard Specifications for Copper Bars for Locomotive Staybolts (B 12 - 42) be withdrawn and that Emergency Alternate Provisions EA - B 16 applying to the Standard Specifications for Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 - 44) be retained. It was also recommended that revisions be incorporated in the Tentative Specifications for:[3] Naval Brass Rods, Bars, and Shapes (B 21 - 44 T), Copper Rods, Bars, and Shapes (B 133 - 44 T), Phosphor Bronze Rods, Bars, and Shapes (B 139 - 44 T), Aluminum Bronze Rods, Bars, and Shapes (B 150 - 44 T), Copper-Nickel-Zinc Alloy Rod, Bar, and Wire (B 151 - 44 T), and Copper Bus Bars, Rods, and Shapes (B 187 - 44 T). Revisions, for immediate adoption, were recommended in the Standard Specifications for: Copper Bars for Locomotive Staybolts (B 12 - 42), Free-Cutting Brass Rod and Bar for Use In Screw Machines (B 16 - 44), Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 44), Manganese Bronze Rods, Bars, and Shapes (B 138 - 43), and Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 - 43). The Tentative Specifications for Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 - 44 T) were recommended for adoption as standard. Among the changes in rod and bar specifications, is the incorporation of straightness tolerances in nearly all cases. The subcommittee also prepared proposed new Tentative Specifications for Beryllium-Copper Alloy Rod and Bar[2] to replace part of the Tentative Specifications for Beryllium-Copper Alloy Rods, Bars, Sheet, Strip, and Wire (B 120 - 41 T). It is planned to rewrite Tentative Specifications B 151 - 44 T to cover only rods and bars and to refer the wire section to Subcommittee A-3 on Wire and Wire Rod for preparation as separate wire specifications and to retain Specifications B 151 - 44 T as tentative until the wire specifications are accepted.[3]

It was recommended that the Advisory Committee be requested to establish definitions of products, for assignment of products to specifications and subcommittees. It was voted that pending action by the Advisory Committee, drawn wire, flat wire, and square wire tolerances be excluded from the specifications under the jurisdiction of Subcommittee A-2. It is the consensus of the subcommittee that the inclusion of tolerances for piston and shafting rod should be deferred pending recommendations from Subcommittee C-2 on Tolerances.

A special committee (B. J. Sirois, J. E. McGraw, and C. H. Davis) submitted a report covering standard edge and corner radii for flat wire, strip, and bar with rolled or drawn edges. The report was accepted, with slight revision, for application to the Tentative Specifications for Copper Rods, Bars, and Shapes (B 133 – 44 T) and for Copper Bus Bars, Rods, and Shapes (B 187 – 44 T) and members of the subcommittee were requested to indicate to what other specifications the report should apply.

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[2] These specifications were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

[3] See Editorial Note, p. 119.

A special committee, under the chairmanship of C. H. Davis, is preparing a section on chemical requirements for inclusion in the Tentative Specifications for Aluminum Bronze Rods, Bars, and Shapes (B 150 – 44 T).

A special committee (G. H. Harnden, B. J. Sirois, and C. H. Davis) prepared an edgewise bending test for incorporation in Tentative Specifications B 187.

A special committee, under the chairmanship of H. V. Schlacks, is to study beryllium-copper alloy rod and bar properties.

A special committee (H. V. Schlacks, B. J. Sirois, and R. B. Hitchcock) was appointed to study methods of measuring rod and bar straightness.

Subcommittee A-3 on Wire and Wire Rod (B. J. Sirois, chairman) recommended revisions in the Tentative Specifications for Phosphor Bronze Wire (B 159 – 44 T), the immediate adoption of revisions in the Standard Specifications for Copper-Silicon Alloy Wire for General Purposes (B 99 – 42), and with slight revision, the adoption as standard of the Tentative Specifications for Brass Wire (B 134 – 44 T). It also prepared proposed new Tentative Specifications for Beryllium-Copper Alloy Wire[2] to replace part of the Tentative Specifications for Beryllium-Copper Alloy Rods, Bars, Sheet, Strip, and Wire (B 120 – 41 T).

The preparation of Specifications for Copper-Nickel-Zinc Alloy Wire[3] to replace part of the Tentative Specifications for Copper-Nickel-Zinc Alloy Rod, Bar, and Wire (B 151 – 44 T), has been assigned to this subcommittee.

Subcommittee A-4 on Pipe and Tube (Alan Morris, chairman, M. A. Buell, secretary) recommended that Emergency Alternate Provisions EA – B 111 and EA – B 135 applying to the Standard Specifications for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 43) and to the Tentative Specifications for Miscellaneous Brass Tubes (B 135 – 43 T) be withdrawn and that the provisions be incorporated in the respective specifications. Revisions were recommended in the Tentative Specifications for: Seamless Copper Tubes (B 75 – 43 T), Miscellaneous Brass Tubes (B 135 – 43 T), and Copper Bus Pipes and Tubes (B 188 – 44 T). Revisions for immediate adoption were recommended in the Standard Specifications for: Copper Pipe, Standard Sizes (B 42 – 43), Brass Pipe, Standard Sizes (B 43 – 42), Seamless Copper Tubing, Bright Annealed (B 68 – 43), Copper Water Tube (B 88 – 41), and Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 43).

It was recommended that Committee B-5 call to the attention of the Copper and Brass Research Association, the difference in the copper content limits in alloys 3 and 4 of Tentative Specifications B 135, compared to the same alloys shown in the CABRA List of Standard Alloys.

Committee B-5 was requested to take up with Committee B-2 on Non-Ferrous Metals and Alloys the fact that type A copper in the Standard Specifications for Seamless Copper Tubing, Bright Annealed (B 68 – 43) and the Tentative Specifications for Copper Tubes (B 75 – 43 T) could not be purchased to meet a maximum of 0.010 per cent phosphorus.

It was recommended that Committee

B-5 take up with A.S.T.M. Headquarters the question of whether it is necessary to retain Standard Specifications for: Seamless Copper Boiler Tubes (B 13 - 41) and Seamless Brass Boiler Tubes (B 14 – 18).

Subcommittee B-1 on Castings, and Ingots for Remelting (G. H. Clamer, chairman, C. S. Cole, secretary) recommended that Emergency Alternate Provisions EA-B 148a be withdrawn and that the provisions be incorporated in the Tentative Specifications for Aluminum Bronze Sand Castings (B 148 – 44 T). It also recommended that Emergency Alternate Provisions EA-B 22b, EA-B 61, EA-B 62b, EA-B 143b, EA-B 145b, and EA-B 146b, be retained. Revisions were recommended in the Tentative Specifications for: Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 – 44 T), Copper-Base Alloys In Ingot Form for Sand Castings (B 30 – 44 T), High-Leaded Tin-Bronze Sand Castings (B 144 – 44 T), Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 – 44 T), Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 44 T), and Aluminum Bronze Sand Castings (B 148 – 44 T). With slight revision, the Tentative Classification of Cast Copper-Base Alloys (B 119 – 40 T) was recommended for adoption as standard. It was recommended that the Standard Specifications for Phosphor Tin (B 51 – 42) be withdrawn since they cover a material no longer in general commercial use.

The proposed specifications for silicon-bronze and silicon-brass castings, which the subcommittee has had under consideration for several years, as noted in previous reports, have been completed and are recommended for publication as the Tentative Specifications for Silicon-Bronze and Silicon-Brass Sand Castings as appended hereto.[2]

Action on the Emergency Alternate Provisions relating to test bars is deferred pending the availability of data now being obtained for the Non-Ferrous Ingot Metal Institute at Battelle Memorial Institute. Standard Specifications for: Phosphor Tin (B 51 – 42), Phosphor Copper (B 52 – 43), and Silicon Copper (B 53 – 43) were assigned to the subcommittee, jurisdiction over these specifications having been recently transferred to Committee B-5 from Committee B-2.

A special committee is to investigate alloys 1A to 6C inclusive, (in Specifications B 30, B 61, B 62, B 143, B 144, B 145, and B 146) with respect to the present copper minima and ranges, and the effect of nickel additions within the maximum nickel permitted under the present specification limits.

A special committee, under the chairmanship of J. W. Bolton, is giving consideration to rewriting the Standard Specifications for: Steam or Valve Bronze Castings (B 61 – 44) and Composition Brass or Ounce Metal Castings (B 62 – 44) in a form which would be satisfactory to the Manufacturers Standardization Society of the Valve and Fittings Industry, the U. S. Coast Guard, and the Boiler Code Committee of the American Society of Mechanical Engineers.

A special committee is to study the writing of specifications for permanent mold and centrifugal castings.

A special committee, consisting of the M.S.S. representatives was appointed to review the problem of whether physical properties or chemical composition shall be of primary importance in casting specifications.

Subcommittee C-1 on Methods of Test. (G. R. Gohn, chairman) recommended that with slight revision, the Tentative Method of Test for Expansion (Pin

Test) of Copper and Copper-Alloy Tubing (B 153 – 41 T) be adopted as standard. With slight revision and subject to editorial correction in Section 3, it recommended that the Tentative Method of Mercurous Nitrate Test for Copper and Copper Alloys (B 154 – 41 T) be adopted as standard.

It was recommended that a standard hydrogen embrittlement test be incorporated with uniform wording in the Standard Specifications for Seamless Copper Tubing, Bright Annealed (B 68 – 43), and in the Tentative Specifications for: Seamless Copper Tubes (B 75 – 43 T), Copper Rods, Bars, and Shapes (B 133 – 44 T), Copper Sheet, Strip, and Plate (B 152 – 44 T), Copper Bus Bars, Rods, and Shapes (B 187 – 44 T), and Copper Bus Pipes and Tubes (B 188 – 44 T).

It was voted to request Committee E-3 on Chemical Analysis of Metals to recommend standard methods of chemical analysis applicable to the specifications under the jurisdiction of Committee B-5 and to advise as to action taken to provide methods of test where none of the present methods are applicable. It was decided that any differences in methods of test used in the B-5 specifications, should be referred to the responsible subcommittees.

A special committee (C. J. Snyder, C. H. Davis, G. H. Harnden, and J. F. Ednie) is preparing a standard rejection clause for specifications under the jurisdiction of Subcommittees A-1, A-2, A-3, and A-4.[3] A separate special committee with J. F. Ednie as coordinating member between the two groups, is to develop a rejection clause applicable to specifications under the jurisdiction of Subcommittee B-1.[3]

A special committee (J. F. Ednie, D. Basch, W. B. Price, H. J. Toner, H. C. Ashley, J. W. Bolton, and C. H. Greenall) is to make recommendations as to the significance of numerical limits in Committee B-5 specifications.

A special committee (D. K. Crampton, G. H. Slagle, A. W. Peterson, R. A. Frye, and N. H. Murdza) is to review the problem of testing thin (0.003 to 0.010 in.) sheet metal.

A special committee (R. A. Lubker, T. C. Merriman, M. A. Buell, and H. C. Ashley) is to make recommendations concerning the testing of full-sized rod stock and the proper gage length of specimen.

The Committee B-5 representative on Committee E-1 on Methods of Testing was requested to obtain from the Section on Indentation Hardness, definite recommendations for the location of Rockwell and Brinell tests on sheet and rod stock.

Subcommittee C-2 on Tolerances (J. E. McGraw, chairman) recommended revision of dimensional tolerances in Committee B-5 specifications to bring them into conformity with current CABRA Standards with particular attention to the Tentative Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 – 42 T) and tube and pipe specifications.[3]

The subcommittee has been requested to look into the question of piston rod and shafting tolerances.

Subcommittee C-3 on Editorial and Publications (C. H. Davis, chairman) is developing plans for editing Committee B-5 specifications for consistency and uniformity of terminology, as well as for the development of lists of definitions of terms.

This report has been submitted to letter ballot of the committee which consists of 105 voting members; 70 members returned their ballots, of whom 63 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

G. H. HARNDEN,
Chairman.

V. P. WEAVER,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 5, a number of recommendations affecting tentatives and the withdrawal of a standard referred to in the report were submitted by Committee B-5 and accepted by the Administrative Committee on Standards on June 27, 1945. The revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Subsequent to the Annual Meeting, Committee B-5 presented to the Administrative Committee on Standards the following recommendations:

New Tentative Specifications for:
Copper-Nickel-Zinc Alloy Wire (B 206 - 46 T).

Tentative Revision of Standard Specifications for:
Copper Rods for Locomotive Staybolts (B 12 - 45),
Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 - 45),
Copper Water Tube (B 88 - 45),
Copper-Silicon Alloy Rods, Bars and Shapes (B 98 - 45),
Copper-Silicon Alloy Wire for General Purposes (B 99 - 45),
Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 45),
Brass Wire (B 134 - 45),
Manganese Bronze Rods, Bars and Shapes (B 138 - 45), and
Leaded Red Brass (Hardware Bronze) Rods, Bars and Shapes (B 140 - 45).

Revision of Tentative Specifications for:
Naval Brass Rods, Bars and Shapes (B 21 - 45 T),
Seamless Copper Tubes (B 75 - 45 T),
Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 - 45 T),
Copper Rods, Bars and Shapes (B 133 - 45 T),
Miscellaneous Brass Tubes (B 135 - 45 T),
Phosphor Bronze Rods, Bars and Shapes (B 139 - 45 T),
Aluminum Bronze Rods, Bars and Shapes (B 150 - 45 T),
Copper-Nickel-Zinc Alloy Rod and Bar (B 151 - 45 T),
Phosphor Bronze Wire (B 159 - 45 T),
Beryllium-Copper Alloy Strip (B 194 - 45 T),
Beryllium-Copper Alloy Rod and Bar (B 196 - 45 T), and
Beryllium-Copper Alloy Wire (B 197 - 45 T).

These recommendations were accepted by the Standards Committee on January 4, 1946. The new and revised tentatives together with the tentative revisions appear in the compilation "A.S.T.M. Standards on Copper and Copper Alloys," April, 1946.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR COPPER AND COPPER ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering copper and copper alloys which are referred to earlier in this report. The standards appear in their present form in the 1944 Book of A.S.T.M. Standards, Part I, and the compilation of "A.S.T.M. Standards on Copper and Copper Alloys," December, 1944.

REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the following 18 tentative specifications be revised as indicated below and continued as tentative.

Tentative Specifications for Naval Brass Rods, Bars, and Shapes (B 21 – 44 T):

Section 1.—Replace the present note in this section by the following: "NOTE.—Rods and bars for hotforging are covered by the Tentative Specifications for Copper-Base Alloy Forging Rods, Bars, and Shapes (A.S.T.M. Designation: B 124)."

Table II.—Replace the present Table II on tension and bend test requirements, by the accompanying Table I.

Section 8.—Delete the present Section 8 retaining the accompanying note and substitute the following:

> 8. A test specimen at least 6 in. in length, but in no case less than twice its diameter or distance between parallel surfaces, shall be totally immersed for 15 min. in the standard mercurous nitrate solution prescribed in the Tentative Method of Mercurous Nitrate Test for Copper and Copper Alloys (A.S.T.M. Designation: B 154). There shall be no cracks in the specimen when examined immediately after it is removed from the solution, rinsed and wiped.

New Section.—Add a new Section 14 on straightness tolerances to read as follows, and as in the accompanying Table II, renumbering the subsequent sections accordingly:

TABLE I.—TENSION AND BEND TEST REQUIREMENTS.

Diameter or Thickness, in.	Tensile Strength, min., psi.	Yield Strength, min., psi.	Elongation in 2 in., min., per cent			Bend Test, Angle of Bend,[a] deg.
			Grade A	Grade B	Grade C	Grade A
Rods and Bars, Soft:						
1.00 and under....	54 000	20 000	35	35	20	180
Over 1.00 to 2.50, incl.	52 000	20 000	40	40	25	180
Over 2.50	50 000	20 000	40	40	30	180
Rods and Bars, Half Hard or Light Annealed:						
0.50 and under....	60 000	27 000	25	25	12	120
Over 0.50 to 1.00, incl.	60 000	27 000	30	25	15	120
Over 1.00 to 2.50, incl.	58 000	26 000	30	25	20	120
Over 2.50 to 3.50, incl.	54 000	25 000	30	30	25	120
Over 3.50	54 000	22 000	30	30	25	120
Rods and Bars, Hard:						
1.00 and under....	67 000	45 000	17	14	10	120
Over 1.00 to 2.50, incl.	62 000	37 000	25	18	15	120
Over 2.50 to 3.50, incl.	54 000	25 000	30	25	20	120
Over 3.50	54 000	22 000	30	25	20	120
Shapes, Soft, All Sizes	56 000	22 000	30	30	20	180

[a] There are no bend test requirements for grades B and C.

> 14. *Straightness Tolerances.*—Unless otherwise specified, the material shall be furnished in straight lengths of which the deviation from absolute straightness shall not exceed the limitations prescribed in Table VII (accompanying Table II).

TABLE II.—STRAIGHTNESS TOLERANCES.

	Maximum Curvature (depth of arc), in.	Portion of Total Length in Which Depth of Arc is Measured, in.
Drawn rods	½	120
Drawn bars and shapes	½	72

Tentative Specifications for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 – 44 T):

Table I.—Replace the present Table I on chemical requirements, by the accompanying Table III.

TABLE III.—CHEMICAL REQUIREMENTS.

Elements Considered	Class A		Class B		Class C		Class D	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Copper, per cent	**79.0**	**82.0**	**82.0**	**85.0**	**78.0**	**82.0**	**86.0**	**89.0**
Tin, per cent	**18.0**	**20.0**	**15.0**	**17.0**	**9.0**	**11.0**	**9.0**	**11.0**
Lead, per cent	....	**0.25**	....	**0.25**	**8.0**	**11.0**	....	**0.30**
Zinc, per cent	....	0.25	....	0.25	....	0.75	1.0	3.0
Nickel, per cent	....	....	....	....	....	**1.0**	....	**1.0**
Iron, per cent	....	0.25	....	0.25	....	0.15	....	0.15
Antimony, per cent	....	....	....	....	....	0.75	....	....
Phosphorus, per cent	....	**1.0**	....	**1.0**	**0.10**	....	....	0.05
Copper plus tin plus lead plus nickel, per cent	....	....	....	....	**98.50**	....	....	....

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

Table II.—For class D change the tensile strength value "33,000" to read "36,000" psi. and the elongation value "14" to read "18" per cent.

Tentative Specifications for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 44 T):

Table II.—Add a footnote reference "*c*" to the minimum copper values and to the maximum nickel values for alloys designated 3A, 3B, 3C, 3D, 3E, 4B, 5A, and 5B. Print the maximum nickel values for these alloys in **bold face type.** In the first column of that portion of the table applying to alloys 1A to 5B, change the last line to read "Copper plus tin plus lead plus nickel, per cent." Make the following changes in percentage values:

Alloy 2A, maximum copper; change from "90.0" to read "89.0."

Alloy 6A, maximum lead; change from "3.0" to read "3.5."

Alloy 6B, maximum lead; change from "2.5" to read "3.5."

Alloy 11B, maximum copper; change from "66.0" to read "67.0."

Tentative Specifications for Seamless Copper Tubes (B 75 – 43 T):

Section 13.—Change to read as follows by the addition of the italicized words:

> 13. It is to be expected that *samples of* types *A*, B, C, and D will pass the following embrittlement test, although the actual performance of the test is not mandatory under the terms of these specifications unless definitely specified: Suitable samples shall be heated to a temperature of 800 *to 875* C. for a period of 20 min. in a furnace containing an atmosphere of hydrogen. After *their* removal from the furnace the samples shall be polished, etched *if desired*, and examined under a microscope at a magnification of not less than 75 diameters. The samples shall not show gassing or open grain structure characteristic of embrittlement.

Section 14.—After Paragraph (*b*) add two new Paragraphs (*c*) and (*d*) to read as follows, relettering present Paragraph (*c*) as (*e*):

> (*c*) *Expansion Test.*—Tentative Method of Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (A.S.T.M. Designation: B 153).

(*d*) *Electrical Resistivity.*—Tentative Method of Test for Resistivity of Copper and Copper-Alloy Electrical Conductors (A.S.T.M. Designation: B 193).

Table II.—Add values of "0.007" and "0.005" to the fourth column for outside diameters over $\frac{1}{8}$ to $\frac{5}{8}$ in. in lines 4 and 5, respectively; also in the fifth column for outside diameters over $\frac{5}{8}$ to 1 in. add values of "0.011", "0.009", "0.0075" and "0.006" in lines 2 to 5, respectively.

Section 17 (*b*).—Change to read as follows by the addition of the italicized words and the omission of the words in brackets:

TABLE IV.—THICKNESS TOLERANCES.

Thickness, in.	Thickness Tolerances, plus and minus,[a] in.							
	STRIP				SHEET			
	8 in. and under in Width	Over 8 to 12 in., incl., in Width	Over 12 to 14 in., incl., in Width	Over 14 to 20 in., incl., in Width	Over 20 to 28 in., incl., in Width	Over 28 to 36 in., incl., in Width	Over 36 to 48 in., incl., in Width	Over 48 to 60 in., incl., in Width
0.004 and under	0.0004	0.0008	0.0008	.....	.....	.....	.....	.....
Over 0.004 to 0.006, incl.	0.0006	0.0010	0.0010	0.0015	.....	.....	.....	.....
Over 0.006 to 0.009, incl.	0.0008	0.0013	0.0013	0.002	.....	.....	.....	.....
Over 0.009 to 0.013, incl.	0.0010	0.0015	0.0015	0.0025	.....	.....	.....	.....
Over 0.013 to 0.017, incl.	0.0013	0.002	0.002	0.0025	.....	.....	.....	.....
Over 0.017 to 0.021, incl.	0.0015	0.0025	0.0025	0.003	.....	.....	.....	.....
Over 0.021 to 0.026, incl.	0.002	0.0025	0.0025	0.003	0.004	0.005	0.006	0.007
Over 0.026 to 0.037, incl.	0.0025	0.003	0.003	0.0035	0.005	0.006	0.007	0.008
Over 0.037 to 0.050, incl.	0.003	0.0035	0.0035	0.004	0.006	0.007	0.008	0.010
Over 0.050 to 0.073, incl.	0.0035	0.004	0.004	0.0045	0.007	0.008	0.010	0.012
Over 0.073 to 0.130, incl.	0.004	0.0045	0.0045	0.005	0.008	0.010	0.012	0.014
Over 0.130 to 0.187, incl.	0.0045	0.005	0.005	0.006	0.010	0.012	0.014	0.016

[a] When tolerances are specified as all plus or all minus, double the above values.

> (*b*) When [specified] straight lengths [with ends included] are supplied *as stock lengths with short lengths included,* at least 75 per cent by weight shall be the length *indicated, subject to a plus and minus tolerance of ½ in.;* [specified;] 25 per cent by weight may be shorter, but no piece shall be less than 50 per cent of the [tube] length *designated* [specified].

Tentative Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 – 42 T):

Section 3 (*a*).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 122 which are to be withdrawn.

Table IV.—Replace the present Table IV on thickness tolerances, by the accompanying Table IV.

Section 15.—Revise this section to read "The width tolerances shall be as prescribed in Table V" (accompanying Table V).

Section 16.—Revise this section to read "The edgewise curvature (depth of arc) in a 72-in. length of metal shall not exceed the amounts prescribed in Table VI (accompanying Table VI).

Section 17.—Revise this section to read as follows:

> 17. (*a*) The material shall be furnished in flat, straight lengths, unless rolls are specified. Rolls shall consist of not more than three lengths, no one of which shall be less than 10 ft. in length.
>
> (*b*) *Acceptable Short Lengths.*—Lengths of flat sheet or strip shall be in accordance with regular practice as prescribed in Table VII (accompanying Table VII).
>
> (*c*) When special lengths are required, they shall be specified in the order.

Section 18.—Delete this section and renumber subsequent sections accordingly.

Tentative Specifications for Copper Rods, Bars, and Shapes (B 133 – 44 T):

Section 1.—Add a note at the end of this section to read as follows: "NOTE.—Rods and bars for hotforging are covered by Tentative Specifications for Copper-Base Alloy Forging Rods, Bars, and Shapes (A.S.T.M. Designation: B 124)."

TABLE V.—WIDTH TOLERANCES.

SLIT METAL AND SLIT METAL WITH ROLLED EDGES

Width, in.	Width Tolerances,[a] plus and minus, in.	
	0.004 to 0.032 in. in Thickness	Over 0.032 to 0.182 in. in Thickness
2 in. and under	0.005	0.010
Over 2 to 8, incl.	0.008	0.013
Over 8 to 14, incl.	0.010	0.015
Over 14 to 20, incl.	0.013	0.018

SQUARE SHEARED METAL
(All Lengths up to 120 in., incl.)

Width, in.	Width Tolerances,[a] plus and minus, in.		
	1/16 in. and under in Thickness	Over 1/16 to 1/8 in., incl., in Thickness	Over 1/8 in. in Thickness
20 and under	1/32	3/64	1/16
Over 20 to 36, incl.	3/64	3/64	1/16
Over 36 to 60, incl.	1/16	1/16	1/16

SAWED METAL
(All widths up to 112 in., incl.)

Length, in.	Width Tolerances,[a] plus and minus, in.	
	1 1/2 and under in Thickness	Over 1 1/2 to 2 1/4 incl., in Thickness
120 and under	1/32	1/16
Over 120 to 200 incl.	1/16	1/16

[a] When tolerances are specified as all plus or all minus, double the above values.

Section 4 (b).—In the last line delete the word "or" and insert in its place the words "low-resistance grade."

Section 4 (c).—Delete the entire paragraph.

Section 4 (d).—Reletter as Paragraph (*c*) and delete the last two lines.

Section 6 (b).—Revise this Paragraph to read as follows by the addition of the italicized words and the omission of the words in brackets:

(*b*) For chemical analysis, equal [amounts] *quantities* of [clean] drillings, millings, sawings, or clippings [of suitable size] shall be taken from [two of the samples selected in accordance with Paragraph (*a*). No lubricant shall be used,] *each sample. The samples shall be cleaned if necessary to remove all dirt, grease, oxide or surface film* and care [shall be] taken not to oxidize, the samples. These shall [then] be thoroughly mixed and [after careful treatment] *carefully treated* with a magnet to remove [possible] *any* iron particles introduced in sampling. Two ounces of the resultant mixture shall be placed in each of three packages, one for the manufacturer, one for the purchaser, and one for an umpire, if necessary (Note).

TABLE VI.—STRAIGHTNESS TOLERANCES, IN.
Maximum Edgewise Curvature (depth of arc) in any 72 in. Portion of the Total Length

SLIT METAL AND SLIT METAL WITH ROLLED EDGES

Width, in.	As Slit	With Rolled Edges or as Straightened
	Shipped in Rolls	Shipped Flat or in Rolls
1/2 and under	3	1/2
Over 1/2 to 1, incl.	1 1/4	1/2
Over 1 to 2, incl.	3/4	1/2
Over 2 to 5, incl.	5/8	1/2
Over 5	1/2	1/2

SQUARE SHEARED METAL
(Not applicable to metal over 120 in. in length)

Thickness, in.	Straightness Tolerances, in.	
	Up to 10 in., incl. in Width	Over 10 in. in Width
1/8 and under	1/16	1/32
Over 1/8 to 3/16, incl.	1/8	3/64
Over 3/16	1/8	1/16

SAWED METAL
(Not applicable to metal over 144 in. in length)

Width, in.	Straightness Tolerances, in.
3 and under	1/16
Over 3	3/64

NOTE.—If an umpire is required he shall be mutually agreeable to the manufacturer and the purchaser. The results of his analysis shall be taken as final.

Section 6 (c).—Revise the first two lines of this Paragraph to read as follows: "Two samples (Section 6 (*a*)), before preparation . . . ."

Section 6 (d).—Delete the word "four" in the third line.

Section 13.—Delete the second sentence of this section and substitute the following: "Suitable samples shall be heated to a temperature of 800 to 875 C. for a period of 20 min. in a furnace containing an atmosphere of hydrogen. After they are removed from the furnace the samples shall be polished, etched if desired, and examined under a microscope at a magnification of not less than 75 diameters. The samples shall not show gassing or open-grain structure characteristic of embrittlement."

TABLE VII.—LENGTH TOLERANCES.[a]

Stock Length, ft.	Indicated Lengths by Weight, min., per cent	Length of Shortest Piece, min., ft.	Indicated Shortest Length by Weight, max., per cent
10 and 12.........	60	4	10
8	70	3	10
6	80	2	10

Length Tolerances for Stock Lengths..............1 in.

Specific Length, ft.	Tolerances	
	Automatic Machine Cut, in.	Resquared Metal, or Square Sheared Metal, in.
Up to 10, incl..................	1/4	1/8
Over 10 to 20, incl............	1/2	...

[a] Tolerances are all plus; if all minus tolerances are desired, use the same values; if tolerances are desired plus and minus, halve the values given.

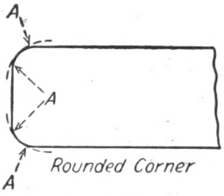
New Section.—Add a new Section 20 on straightness tolerances to read as follows, renumbering the subsequent sections accordingly:

20. *Straightness Tolerances.*—Unless otherwise specified, the material shall be furnished in straight lengths of which the deviation from absolute straightness shall not exceed the limitations prescribed in Table VI (accompanying Table II).

Section 20.—Renumber this section as Section 21, change the title to read "Edge and Corner Radii" and revise Paragraphs (*b*), (*c*), (*d*), and (*e*) to read as follows:

(*b*) *Square Corners.*—Unless otherwise specified, bars shall be finished with commercially square corners with a maximum permissible radius of 1/32 in. for bars over 3/16 in. in thickness.

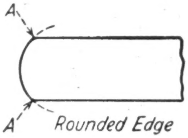
(*c*) *Rounded Corners.*—When specified, bars may be finished with corners rounded as shown in Fig. 1 to a quarter circle with a radius of 1/16 in. for bars over 3/16 in. in thickness. The tolerance on the radius shall be plus and minus 25 per cent.



NOTE.—The arc shall not necessarily be tangent at points *A* but the product shall be commercially free from sharp, rough or projecting edges.

FIG. 1.—Rounded Corners.

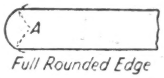
(*d*) *Rounded Edge.*—When specified, bars may be finished with edges rounded as shown in Fig. 2, the radius of curvature being 1¼ times the thickness of the bar for bars over 3/16 in. in thickness. The tolerance on the radius shall be one fourth the thickness of the bar.



NOTE.—The arc shall be substantially symmetrical with the axis of the product. The corners, *A*, will usually be sharp but shall not have rough or projecting edges.

FIG. 2.—Rounded Edge.

(*e*) *Full Rounded Edge.*—When specified, bars may be finished with substantially uniform round edges, the radius of curvature being approximately one-half the thickness of the product, as shown in Fig. 3, but in no case to exceed one half the thickness of the product by more than 25 per cent.



Note.—The arc shall not necessarily be tangent at points *A* but shall be substantially symmetrical with the axis of the product, and the product shall be commercially free from sharp, rough or projecting edges.

Fig. 3.—Full Rounded Edge.

(*f*) *Shapes.*—Products with edge or corner contours other than shown in Paragraphs (*a*) to (*e*) are classified as shapes.

Tentative Specifications for Miscellaneous Brass Tubes (B 135 – 43 T):

Section 1.—Change line 3 to read "Six alloys . . . ", and add to the table of nominal compositions alloy No. 6 with nominal composition as follows: Copper 60 per cent, Zinc 39 per cent, and Lead 1.0 per cent.

Section 3 (*a*).—Revise this section by including a reference to Emergency Specifications ES – 7, thereby eliminating the necessity of the Emergency Alternate Provisions EA – B 135 which are to be withdrawn.

Section 4.—Add a new alloy No. 6 to the table in this section with a chemical composition as follows: Copper 59.0 to 62.0 per cent, Lead 0.9 to 1.4 per cent, Iron 0.15 max. per cent, Zinc remainder.

Tables I and II.—Add alloy No. 6 to the heading for the (60 Cu, 40 Zn) group at the bottom of these tables.

Section 7 (*b*).—Change line 3 to read as follows: "Alloys Nos. 5 and 6 are supplied only . . . ."

Section 11.—Delete the last sentence of this section.

Section 14.—Add to the bottom of the table in this section the following: "Alloy No. 6, Leaded Muntz metal . . . 0.304."

Table III.—Make the same additions as recommended above for Table II of Specifications B 75.

Table V.—Change the note under the title of this table to read as follows: "*Precision Cutting:* This table represents the tolerances to be expected in normal mill practice. Precision cutting can be done to closer tolerances and for such tolerances the manufacturer should be consulted."

TABLE VIII.—TENSILE REQUIREMENTS FOR RODS AND BARS.

Temper	Diameter or Distance Between Parallel Faces, in.	Tensile Strength, psi.		Elongation in 2 in., min. per cent
		Min.	Max.	
Grade A				
Soft	Rounds under 0.250	40 000	58 000	....
Hard	Rounds under 0.250	80 000	128 000	....
	Rounds and Hexagons:			
	0.250 to 0.500	70 000	....	12.0
	0.501 to 1.000	60 000	....	15.0
	1.001 and over	55 000	....	20.0
	Squares and Rectangles:			
	0.250 to 0.375	60 000	....	10.0
	0.376 and over	55 000	....	15.0
Spring	Rounds:			
	Under 0.026	125 000	....	....
	0.026 to 0.0625	115 000	....	....
	0.0626 to 0.125	110 000	....	....
	0.126 to 0.250	105 000	....	3.5
	0.251 to 0.375	100 000	....	5.0
	0.376 to 0.500	90 000	....	9.0
Grades B1 and B2				
Hard	Rounds and Hexagons:			
	0.250 to 0.500	60 000	....	12.0
	0.501 to 1.000	55 000	....	15.0
	1.001 and over	50 000	....	20.0
	Squares and Rectangles:			
	0.250 to 0.375	55 000	....	10.0
	0.376 and over	50 000	....	15.0
Grade C				
Soft	Rounds under 0.250	53 000	68 000	....
Hard	Rounds under 0.250	105 000	150 000	....
	Rounds and Hexagons:			
	0.250 to 0.500	85 000	....	12.0
	0.501 to 1.000	75 000	....	15.0
	1.001 and over	60 000	....	20.0
	Squares and Rectangles:			
	0.250 to 0.375	68 000	....	10.0
	0.376 and over	60 000	....	15.0
Grade D				
Soft	Rounds under 0.250	60 000	75 000	....
Hard	Rounds under 0.250	105 000	160 000	....
	Rounds and Hexagons:			
	0.250 to 0.500	95 000	....	12.0
	0.501 to 1.000	85 000	....	15.0
	1.001 and over	70 000	....	20.0
	Squares and Rectangles:			
	0.250 to 0.375	76 000	....	10.0
	0.376 and over	70 000	....	15.0

Section 16 (b).—Make the same change as recommended above in Section 17 (*b*) of Specifications B 75.

Tentative Specifications for Phosphor Bronze Rods, Bars, and Shapes (B 139 - 44 T):

Section 3 (a).—Delete reference to phosphor tin.

Table II.—Replace the present Table II on tensile requirements, by the accompanying Table VIII.

New Section.—Add a new Section 14 on straightness tolerances to read as recommended above for Specifications B 21, renumbering the subsequent sections accordingly.

Tentative Specifications for High-Leaded Tin-Bronze Sand Castings (B 144 - 44 T):

Table II.—Add a new footnote *b* to read: "In determining copper minimum, copper may be calculated as copper plus nickel." The reference to this footnote applies against the values for copper minimum and nickel maximum for alloys 3A to 3E, inclusive. Print the values for nickel maximum in bold face type. Reletter the present footnotes *b* and *c* and their references to read "*c*" and "*d*," respectively.

Tentative Specifications for Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 - 44 T):

Table II.—Apply footnote reference "*a*" to copper minimum and nickel maximum of alloys 4B, 5A, and 5B, and designate nickel values in bold face type.

Tentative Specifications for Leaded Yellow Brass Sand Castings for General Purposes (B 146 - 44 T):

Table II.—Change the requirements for maximum lead for alloy 6A from "3.5" to read "3.75" per cent, and for alloy 6B from "3.0" to read "3.75" per cent.

Tentative Specifications for Aluminum-Bronze Sand Castings (B 148 - 44 T):

Section 3 (b).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the necessity of the Emergency Alternate Provisions EA-B 148a which are to be withdrawn.

Tentative Specifications for Aluminum Bronze Rods, Bars, and Shapes (B 150 - 44 T):

Section 1.—Add a note at the end of this section to read as follows: "NOTE.—Rods and bars for hotforging are covered by the Tentative Specifications for Copper-Base Alloy Forging Rods, Bars, and Shapes (A.S.T.M. Designation: B 124)."

Section 8.—Revise this section as recommended above in Section 8 of Specifications B 21.

New Section.—Add a new Section 14 on straightness tolerances to read as recommended above for new Section 14 in Specifications B 21, renumbering the subsequent sections accordingly.

Tentative Specifications for Copper-Nickel-Zinc Alloy Rod, Bar, and Wire (B 151 - 44 T):

New Section.—Add a new Section 15 on straightness tolerances to read as recommended above for new Section 14 in Specifications B 21, renumbering the subsequent sections accordingly.

Tentative Specifications for Copper Sheet, Strip, and Plate (B 152 - 44 T):

Section 2.—Add a new item 3, to read as follows: "(*3*) Whether the resistivity test is required for either type A or C (Sections 1 and 14)," and renumber the subsequent items accordingly.

Section 4.—In the table in this section change the minimum copper (plus silver) requirement for type C from "99.90" to read "99.92" per cent, and for type E from "99.45" to read "99.40" per cent.

Section 13.—Revise line 12 of this section to read as follows: ". . . shall be polished, etched if desired, . . ."

Section 14.—Revise the first sentence to read as follows: "When specified in the order, the electrical resistivity determined on samples of types A and C copper shall not exceed. . . ." In the table of resistivity values, change the present designated condition "Hard (cold-rolled)" to read "Cold-rolled tempers." Change the resistivity values "0.15614" and "0.15940" to read "0.15328" and "0.15775," respectively. In the note, change the resistivity values "0.15614" and "0.15940" to read "0.15328" and "0.15775," respectively, and the conductivity values "98.16" and "96.16" to read "100" and "97.16," respectively.

Section 16.—Add a new Paragraph (*d*) to read as follows: "(*d*) *Electrical Resistivity.*—Tentative Method of Test for Resistivity of Copper and Copper-Alloy Electrical Conductors (A.S.T.M. Designation: B 193)."

Table V.—Change the subhead "Slit Metal and Rolled-Edge Metal" to read "Slit Metal and Slit Metal with Rolled Edges."

Tentative Specifications for Phosphor Bronze Wire (B 159 – 44 T):

Section 1.—Add a new Paragraph (*c*) to read as follows: "(*c*) Material in straight lengths (rod) is covered by Tentative Specifications for Phosphor Bronze Rods, Bars, and Shapes (A.S.T.M. Designation: B 139)."

Section 3 (*a*).—Replace reference to "Phosphor Tin B 51" with "Phosphor Copper B 52."

Tables II and III.—Revise footnote *a* to read as follows: "Material in straight lengths (rod) is covered by Tentative Specifications for Phosphor Bronze Rods, Bars, and Shapes (A.S.T.M. Designation: B 139)." In Table III delete elongation values "1.5" and "2.0" for wire 0.125 in. in diameter and under.

Section 10 (*b*).—In the first three lines delete the words "of round sections or the distance between parallel surfaces in the case of other sections."

Table IV.—Delete the last column of the present table giving tolerances for hexagonal and octagonal wire, and change table heading accordingly.

Tentative Specifications For Copper Bus Bars, Rods, and Shapes (B 187 – 44 T):

Section 5.—In Paragraph (*b*) add the following at the end of the first sentence: ". . . and with no apparent evidence of slivers or other imperfections."

Add a new Paragraph (*c*) to read as follows:

> (*c*) *Edgewise Bend Test.*—The material shall be capable of being bent cold edgewise through 90 deg. around a mandrel having a radius as shown in the following table:
>
> | Width of Bus Bar, in. | Mandrel Radius, in. |
> |---|---|
> | Up to ½, incl. | ½ |
> | Over ½ to 1, incl. | 1 |
> | Over 1 to 1½, incl. | 1½ |
> | For widths over 1½ increasing by increments of ½ | Radii over 1½ increase by increments of ½ |
>
> The actual performance of this test is not mandatory under the terms of these specifications unless definitely specified in the purchase order and, when so specified, the test shall be performed only for bars up to and including 4 in. in width. It is expected that bus bars over 4 in. in width as furnished shall, if necessary for fabricating purposes, be capable of being bent over mandrels of the specified radii and failure to meet satisfactorily this requirement shall constitute cause for rejection.

Section 7.—Change lines 12 and 13 to read as follows: ". . . samples shall be polished, etched if desired, and examined, . . ."

Section 13.—Replace this section with the same section on straightness tolerances recommended above as a new Section 14 in Specifications B 21.

Section 14.—Change the title of this section to read "Edge and Corner Radii," and revise Paragraphs (*b*), (*c*), (*d*), and (*e*) to read as recommended above in Section 20 of Specifications B 133.

Section 15.—Revise the first sentence to read as follows: "The material shall be free from blisters, slivers, and scale, as well as from all other imperfections not consistent. . . ."

Tentative Specifications For Copper Bus Pipes and Tubes (B 188 – 44 T):

Section 7.—Change lines 12 and 13 to read: ". . . the samples shall be polished, etched if desired, and examined. . . ."

Section 10.—In Paragraph (*a*), add a reference to the Tentative Method of Test for Resistivity of Copper and Copper-Alloy Electrical Conductors (A.S.-T.M. Designation: B 193).

Table II.—Delete the dimensions and weights for pipe sizes 4½, 7, 9, and 11 in.

Section 12.—Delete Paragraph (*f*) and reletter the subsequent paragraph accordingly.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends, for immediate adoption, revisions in 11 specifications, as indicated below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Specifications for Copper Bars For Locomotive Staybolts (B 12 – 42):

Title.—Change the title to read: "Copper Rods For Locomotive Staybolts," and substitute the term "rod" for "bar" throughout the Specifications.

Standard Specifications For Free-Cutting Brass Rod and Bar For Use in Screw Machines (B 16 – 44):

Section 1.—Delete the note in Paragraph (*b*).

TABLE IX.—DIMENSIONS AND WEIGHTS OF COPPER PIPE, STANDARD PIPE SIZES.

Pipe Size, in.	Nominal Dimensions, in.			Cross-Sectional Area of Bore, sq. in.	Weight, lb. per ft.
	Outside Diameter	Inside Diameter	Wall Thickness		
		REGULAR			
⅛	0.405	0.281	0.062	0.062	0.259
¼	0.540	0.376	0.082	0.110	0.457
⅜	0.675	0.495	0.090	0.192	0.641
½	0.840	0.626	0.107	0.307	0.955
¾	1.050	0.822	0.114	0.531	1.30
1	1.315	1.063	0.126	0.887	1.82
1¼	1.660	1.368	0.146	1.47	2.69
1½	1.900	1.600	0.150	2.01	3.20
2	2.375	2.063	0.156	3.34	4.22
2½	2.875	2.501	0.187	4.91	6.12
3	3.500	3.062	0.219	7.37	8.75
3½	4.000	3.500	0.250	9.62	11.4
4	4.500	4.000	0.250	12.6	12.9
5	5.562	5.062	0.250	20.1	16.2
6	6.625	6.125	0.250	29.5	19.4
8	8.625	8.001	0.312	50.3	31.6
10	10.750	10.020	0.365	78.8	46.2
12	12.750	12.000	0.375	113.	56.5
		EXTRA STRONG			
⅛	0.405	0.205	0.100	0.033	0.371
¼	0.540	0.294	0.123	0.068	0.625
⅜	0.675	0.421	0.127	0.139	0.847
½	0.840	0.542	0.149	0.231	1.25
¾	1.050	0.736	0.157	0.425	1.71
1	1.315	0.951	0.182	0.710	2.51
1¼	1.660	1.272	0.194	1.27	3.46
1½	1.900	1.494	0.203	1.75	4.19
2	2.375	1.933	0.221	2.94	5.80
2½	2.875	2.315	0.280	4.21	8.85
3	3.500	2.892	0.304	6.57	11.8
3½	4.000	3.358	0.321	8.86	14.4
4	4.500	3.818	0.341	11.5	17.3
5	5.562	4.812	0.375	18.2	23.7
6	6.625	5.751	0.437	26.0	32.9
8	8.625	7.625	0.500	45.7	49.5
10	10.750	9.750	0.500	74.7	62.4

Section 4.—Delete the note in this section.

New Section.—Add a new Section 14 on straightness tolerances to read as recommended above in Section 14 for Specifications B 21, renumbering the subsequent sections accordingly.

Standard Specifications for Copper Pipe, Standard Sizes (B 42 – 43):

Section 2.—Delete Item (*4*) (*c*).

Section 7.—Revise the first sentence to read as follows: "Specimens selected for test shall, after annealing, withstand ...." Add a new sentence to read as follows: "The test shall be made in accordance with the Tentative Method of Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (A.S.T.M. Designation: B 153)."

Section 10.—At the end of this section add a sentence to read as follows: "At the option of the manufacturer annealed pipe with wall thicknesses up to 0.083 in. inclusive, may be tested in the hard-drawn condition, prior to annealing."

TABLE X.—WALL THICKNESS TOLERANCES.

Pipe Size, in.	Wall Thickness Tolerances, per cent[a]	
	Minus	Plus
6 and under	5	limited only by weight tolerances
Over 6 to 8, incl.	7	
Over 8	8	

[a] Expressed to the nearest 0.001 in.

Table I.—Replace Table I on standard dimensions and weights of copper pipe with the accompanying Table IX.

Section 13.—Change the title to read "Weight and Wall Thickness Tolerances."

Section 13 (*a*).—Change heading in the table to read "Tolerance, plus and minus, per cent."

Section 13 (*b*).—Change the title to read "Wall Thickness," and replace the present table in this paragraph with the accompanying Table X.

Table II.—Change the note on precision cutting under the title of this table to read the same as recommended above in Table V of Specifications B 135.

Section 14 (*b*).—Change to read the same as recommended above in Section 17 (*b*) of Specifications B 75.

Section 14 (*c*).—Delete and reletter the subsequent paragraphs accordingly.

Section 14 (*d*).—Reletter and change to read as follows: "(*c*) The angle of cut of the end of any pipe may depart from square by not more than 0.010 in. for pipe up to and including $\frac{5}{8}$ in. in outside diameter; for pipe over $\frac{5}{8}$ in. in outside diameter, by not more than 0.016 in. per in. of diameter."

Section 14 (*e*).—Reletter and change to read as follows: "(*d*) For drawn unannealed pipe in straight lengths, neither the major nor minor diameter shall vary more than 1 per cent from the specified diameter. For annealed pipe in straight lengths no out-of-round tolerance is established."

Standard Specifications for Brass Pipe, Standard Sizes (B 43 – 42):

Section 2.—Delete item 4 (*c*).

Section 7.—Change first sentence to read "Specimens selected for test shall, after annealing, withstand. . . ."

Section 8.—Delete the last sentence.

Table I.—Replace Table I on standard dimensions and weights of brass pipe with the accompanying Table XI.

Section 14.—Change the title of this section to read "Weight and Wall Thickness Tolerances."

Section 14 (*a*).—Change heading in the table to read "Tolerances, per cent, plus and minus."

Section 14 (*b*).—Change title to read "Wall Thickness" and replace the present table in this paragraph with the accompanying Table X.

Table II.—Under the title of this table add the note on precision cutting to read the same as recommended above in Table V of Specifications B 135.

Section 15 (*b*).—Revise to read as follows: "(*b*) At least 75 per cent by weight shall be the length indicated, subject to a plus and minus tolerance of $\frac{1}{2}$ in. Twenty-five per cent by weight may be shorter, but no piece shall be less than 50 per cent of the length designated."

TABLE XI.—DIMENSIONS AND WEIGHTS OF BRASS PIPE, STANDARD PIPE SIZES.

Pipe Size, in.	Nominal Dimensions, in.			Cross-Sectional Area of Bore, sq. in.	Weight, lb. per ft.	
	Outside Diameter	Inside Diameter	Wall Thickness		Yellow Brass	Red Brass
			REGULAR			
1/8	0.405	0.281	0.062	0.062	0.246	0.363
1/4	0.540	0.376	0.082	0.110	0.435	0.611
3/8	0.675	0.495	0.090	0.192	0.609	0.829
1/2	0.840	0.626	0.107	0.307	0.908	1.23
3/4	1.050	0.822	0.114	0.531	1.23	1.67
1	1.315	1.063	0.126	0.887	1.73	2.46
1 1/4	1.660	1.368	0.146	1.47	2.56	3.39
1 1/2	1.900	1.600	0.150	2.01	3.04	4.10
2	2.375	2.063	0.156	3.34	4.01	5.67
2 1/2	2.875	2.501	0.187	4.91	5.82	8.66
3	3.500	3.062	0.219	7.37	8.32	11.6
3 1/2	4.000	3.500	0.250	9.62	10.9	14.1
4	4.500	4.000	0.250	12.6	12.3	16.9
5	5.562	5.062	0.250	20.1	15.4	23.2
6	6.625	6.125	0.250	29.5	18.4	32.2
8	8.625	8.001	0.312	50.3	30.0	48.4
10	10.750	10.020	0.365	78.8	43.9	61.1
12	12.750	12.000	0.375	113.	53.7	....
			EXTRA STRONG			
1/8	0.405	0.205	0.100	0.033	0.353	....
1/4	0.540	0.294	0.123	0.068	0.594	....
3/8	0.675	0.421	0.127	0.139	0.805	....
1/2	0.840	0.542	0.149	0.231	1.19	....
3/4	1.050	0.736	0.157	0.425	1.62	....
1	1.315	0.951	0.182	0.710	2.39	....
1 1/4	1.660	1.272	0.194	1.27	3.29	....
1 1/2	1.900	1.494	0.203	1.75	3.99	....
2	2.375	1.933	0.221	2.94	5.51	....
2 1/2	2.875	2.315	0.280	4.21	8.4	....
3	3.500	2.892	0.304	6.57	11.21	....
3 1/2	4.000	3.358	0.321	8.86	13.7	....
4	4.500	3.818	0.341	11.5	16.4	....
5	5.562	4.812	0.375	18.2	22.5	....
6	6.625	5.751	0.437	26.0	31.3	....
8	8.625	7.625	0.500	45.7	47.0	....
10	10.750	9.750	0.500	74.7	59.3	....

Section 15 (*c*).—Revise this paragraph to read as recommended above in Section 14 (*d*) of Specifications B 42.

Section 15 (*d*).—Add a new Paragraph (*d*) to this section to read as recommended above in Section 14 (*e*) of Specifications B 42.

Standard Specifications for Seamless Copper Tubing, Bright Annealed (B 68 – 43):

Section 10.—Change first sentence to read as follows: "It is to be expected that samples of all types of copper in these specifications will pass. . . ." Starting at line 7, change to read: "Suitable samples shall be heated to a temperature of 800 to 875 C. . . ." Starting at line 11, change to read: "After their removal from the furnace, the samples shall be polished, etched if desired, and examined at a magnification of not less than 75 diameters."

Table I.—Make the same changes in this table as recommended above in Table II of Specifications B 75.

Section 14 (*b*).—Change this paragraph to read as recommended above in Section 15 (*b*) of Specifications B 43.

Standard Specifications for Copper Water Tube (B 88 – 41):

Section 2.—Delete item 4 (*c*) and reletter item (*d*) accordingly.

Section 12.—Add a new Paragraph (*c*) to read as follows: "(*c*) *Expansion Test.*—Standard Method of Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (A.S.T.M. Designation: B 153)."

Section 16 (*b*).—Change to read as recommended above in Section 15 (*b*) of Specifications B 43.

Section 16 (*c*).—Delete this paragraph and reletter subsequent paragraphs accordingly.

Standard Specifications for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 44):

Section 1.—Change the first sentence to read as follows: "These specifications cover copper-silicon alloy rods, bars, and shapes." Add a note at the end of this section to read "NOTE.—Rods and bars for reforging are covered by the Tentative Specifications for Copper-Base Alloy

Forging Rods, Bars, and Shapes (A.S.T.M. Designation: B 124)."

New Section.—Add a new Section 13 on straightness tolerances to read as recommended above for Section 14 in Specifications B 21, renumbering the subsequent sections accordingly.

Standard Specifications for Copper-Silicon Alloy Wire For General Purposes (B 99 – 42):

Section 1.—Change the first sentence to read: "These specifications cover round, hexagonal, and octagonal copper-silicon alloy wire. . . . "

TABLE XII.—DIMENSIONAL TOLERANCES.

Diameter or Distance between Parallel Surfaces, in.	Tolerances, plus and minus,[a] in.			
	Types A, C, D		Type B	
	Round	Hexagon, Octagon	Round	Hexagon, Octagon
Up to 0.010, incl.	0.0002	....	0.0001	....
Over 0.010 to 0.020, incl.	0.0003	....	0.0002	....
Over 0.020 to 0.030, incl.	0.0005	....	0.0003	....
Over 0.030 to 0.040, incl.	0.0007	0.002	0.0004	0.0008
Over 0.040 to 0.050, incl.	0.0008	0.003	0.0005	0.0010
Over 0.050 to 0.060, incl.	0.0010	0.003	0.0006	0.0012
Over 0.060 to 0.080, incl.	0.0015	0.004	0.0008	0.0016
Over 0.080 to 0.150, incl.	0.002	0.004	0.0010	0.002
Over 0.150 to 0.500, incl.	0.002	0.004	0.0015	0.003
Over 0.500 to 0.750, incl.	0.003	....	0.002	....

[a] When tolerances are specified as all plus or all minus, double the above values.

Section 2.—Change item (*3*) to read "Diameter or distance between parallel surfaces (Section 11)."

Table II.—Make the following changes to this table:

(*1*) Change footnote *d* to footnote *f* and accordingly change the reference to it in the table after the word "spring" in the first column.

(*2*) Add a new footnote *d* to read as follows: "Hard temper is not generally available in sizes over ½ in.," and add references to it in the right-hand column after the values 115,000 for types A, C, and D alloy wire and after the value of 90,000 for type B alloy wire.

(*3*) Add a new footnote *e* to read as follows: "Spring temper is not generally available in sizes over ⅜ in.," and add references to it in the right-hand column after the values of 130,000 for types A, C, and D alloy wire and after the value of 100.000 for type B alloy wire.

Section 11 (*b*).—Revise to read as follows: "The diameter of round sections or the distance between parallel surfaces in the case of other sections shall not vary from that specified by more than the amounts prescribed in the accompanying Table XII."

Standard Specifications for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 – 43):

Section 3 (*a*).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 111 which are to be withdrawn.

Section 3 (*b*).—Revise to read as follows: "Clean, new scrap resulting from manufacturing operations upon material complying with these specifications or clean scrap composed of materials of equal purity may be used."

Table I.—Make the following changes to this table:

(*1*) For aluminum bronze: Add value of "0.35 max." under Arsenic, per cent.

(*2*) For 70–30 copper nickel: Change value of maximum iron from "0.5" to read "0.6" per cent.

(*3*) For 80-20 copper nickel (type A and type B): Change value of maximum iron from "0.5" to read "0.6" per cent.

(*4*) For arsenical copper: Change value of minimum copper from "99.45" to read "99.40" per cent.

Section 8.—Add a new Paragraph (*c*) to read as follows: "(*c*) The test shall be made as prescribed in the Standard Method of Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (A.S.T.M. Designation: B 153)."

New Section.—Add a new Section 9 headed "Flattening Test" to read as follows, renumbering the subsequent Sections accordingly: "9. Test tubes in the annealed condition shall be flattened on different elements throughout the lengths remaining after specimens for the expanding and metallographic tests have been taken. Each element shall be slowly flattened by one stroke of a press. The term 'flattened' shall be interpreted as follows: A micrometer caliper set at three times the wall thickness shall pass over the tube freely throughout the flattened part except at the points where the change in element of flattening takes place."

Section 9.—Renumber as Section 10 and add a sentence to read as follows: "The mercurous nitrate test is not required for copper or arsenical copper."

Standard Specifications for Manganese Bronze Rods, Bars, and Shapes (B 138 – 43):

Section 1.—Add a note at the end of this section to read as follows: "NOTE.—Rods and bars for hotforging are covered by the Tentative Specifications for Copper-Base Alloy Forging Rods, Bars, and Shapes (A.S.T.M. Designation: B 124)."

Section 8.—Revise this section as recommended above in Section 8 of Specifications B 21.

New Section.—Add a new Section 14 on straightness tolerances to read as recommended above for new Section 14 in Specifications B 21, and renumber the subsequent sections accordingly.

Standard Specifications for Leaded Red Brass (Hardware Bronze) Rods, Bars and Shapes (B 140 – 43):

New Section.—Add a new Section 11 on straightness tolerances to read as recommended above for new Section 14 in Specifications B 21.

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following six tentatives be approved for reference to letter ballot of the Society for adoption as standard, with revisions in five as indicated.

Tentative Specifications for Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 – 44 T): without revision.

Tentative Classification of Cast Copper-Base Alloys (B 119 – 40 T):

Add "(Manganese Bronze)" in the first column of the classifications designated "High-Strength Yellow Brass." Add a scope clause calling attention to the fact that this is a classification, not a specification; also include references to the available A.S.T.M. specifications by appropriate notes under "Remarks." The classification, as revised, is appended hereto.[1]

Tentative Specifications for Brass Wire (B 134 – 44 T):

Section 1.—Change the first sentence to read as follows: "These specifications cover round, hexagonal, octagonal, rectangular, and square brass wire."

Section 2.—Change item (*3*) to read: "Diameter or distance between parallel surfaces (Section 12)."

Tentative Method of Test for Expansion (Pin Test) of Copper and Copper Alloy Tubing (B 153 – 41 T):

Section 1.—Revise to read as follows: "This method covers the expansion pin test for copper and copper-alloy tubing in sizes up to and including 4 in. in outside diameter."

Tentative Method of Mercurous Nitrate Test for Copper and Copper Alloys (B 154 – 41 T):

Section 3.—Correct editorially, in line 4 of Paragraph (*a*), line 4 of Procedure A, line 7 of Procedure B and line 8 of Paragraph (*c*), the amount of nitric acid from "10 ml." to read "13 ml." This will bring the method into conformity with the 1941 preprint of the Report of Committee B-5, which was approved by the Society without change.

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[1] This revised tentative classification was accepted by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Section 4(a).—Add to the end of this paragraph the following: " . . . and shall be suitably degreased before testing."

Section 5.—After line 15 which reads "wiped off immediately with a clean rag," add a new sentence to read as follows: "In general the specimens shall be examined at once, unless otherwise provided for in the individual specifications."

Tentative Specifications for Copper-Alloy Condenser Tube Plates (B 171 – 42 T):

Section 3 (*a*).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 171 which are to be withdrawn.

Table I.—Change the maximum iron content of copper-nickel alloy from "0.50" to read "0.60".

ADOPTION OF TENTATIVE REVISIONS OF STANDARDS AS STANDARD

The committee recommends the adoption as standard of the tentative revisions[2] issued in 1944 in the following two standard specifications:

Standard Specifications for Manganese Bronze Rods, Bars, and Shapes (B 138 – 43).

Standard Specifications for Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 43).

WITHDRAWAL OF STANDARDS

Standard Specifications for Phosphor Tin (B 51 – 42):

The committee recommends that Standard Specifications B 51 be withdrawn, since they cover a material no longer in general use.

Tentative Specifications for Beryllium-Copper Alloy Rods, Bars, Sheet, Strip, and Wire (B 120 – 41 T):

The committee recommends that Specifications B 120 be withdrawn since they are superseded by four new beryllium-copper alloy specifications appearing later in this report.

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[2] 1944 Book of A.S.T.M. Standards, Part I, pp. 2003 to 2005.

REPORT OF COMMITTEE B-6

ON

DIE-CAST METALS AND ALLOYS*

Committee B-6 on Die-Cast Metals and Alloys held a meeting in New York, N. Y., on June 28, 1944, with an attendance of 26.

A balance of $2500 was reported by Society Headquarters in the fund of Committee B-6 as of December 31, 1944.

At the present time the committee consists of 82 members, of whom 39 are classified as producers, 21 as consumers, and 22 as general interest members.

Subsequent to the 1944 Annual Meeting, Committee B-6 recommended to Committee E-10 on Standards that the Emergency Alternate Provisions applying to the Standard Specifications for Aluminum-Base Alloy Die Castings (EA – B 85a) and to the Standard Specifications for Zinc-Base Alloy Die Castings (EA – B 86b) be withdrawn. This recommendation was accepted by Committee E-10 on August 28, 1944.

I. TENTATIVE SPECIFICATIONS CONTINUED AS TENTATIVE

The committee recommends that the Tentative Specifications for Copper-Base (Brass) Alloy Die Castings (B 176 – 42 T)[1] and the Tentative Specifications for Special Quality Zinc-Base Alloy Die Castings (B 186 – 42 T)[1] be continued as tentative without revision.

II. EMERGENCY SPECIFICATIONS CONTINUED AS EMERGENCY STANDARDS

The committee recommends that the Emergency Specifications for Special Quality Aluminum-Base Alloy Die Castings (ES – 29)[1] and the Emergency Specifications for Special Quality Magnesium-Base Alloy Die Castings (ES – 40)[1] be continued as Emergency Standards without revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 82 members; 59 members returned their ballots with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. TENTATIVE SPECIFICATIONS CONTINUED AS TENTATIVE			
Spec. for Copper-Base (Brass Alloy Die Castings (B 176 – 42 T)	38	0	23
Spec. for Special Quality Zinc-Base Alloy Die Castings (B 186-42 T)........................	41	3	16
II. EMERGENCY SPECIFICATIONS CONTINUED AS EMERGENCY STANDARDS			
Emergency Spec. for Special Quality Aluminum-Base Alloy Die Castings (ES – 29)........	39	6	16
Emergency Spec. for Special Quality Magnesium-Base Alloy Die Castings (ES – 40)........	39	6	16

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum-Base Die Casting Alloys (J. J. Bowman, chairman) recommended that the Standard Specifications for Aluminum-Base Alloy Die Castings (B 85 – 42) be revised and reverted to tentative and that Emergency Alternate Provisions EA – B 85a be withdrawn. In addition the subcommittee approved editorial revisions in Emergency Specifications ES - 29 consisting of changing the title to read "Special Quality Aluminum-Base Alloy Die Castings" and referring to the product in the text of the specifications as "special quality die castings."

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 Book of A.S.T.M. Standards, Part I.

The atmospheric exposure testing of test bars of alloys G2 (8 per cent magnesium, remainder aluminum) and SG2 (9.5 per cent silicon, 0.5 per cent magnesium, remainder aluminum) was started in November, 1944. The exposure tests are being conducted in a seacoast (Sandy Hook, N. J.) and an industrial (New York, N. Y.) atmosphere.

Subcommittee II on Zinc-Base Die Casting Alloys (A. E. Weiss, chairman) approved editorial revisions in the Tentative Specifications B 186 - 42 T consisting of changing the title to read "Special Quality Zinc-Base Alloy Die Castings" and referring to the product in the text of the specifications as "special quality die castings."

A special sub-subcommittee, consisting of Messrs. J. R. Townsend, D. L. Colwell, D. Basch, and B. E. Sandell has under consideration revisions in the existing mechanical property values in the Standard Specifications for Zinc-Base Alloy Die Castings (B 86 - 43). These same revised properties are to be incorporated, along with other proposed revisions, in Tentative Specifications B 186 - 42 T.

A recommendation was made to Committee B-2 on Non-Ferrous Metals and Alloys that the impurity limits in the special high grade slab zinc in Standard Specifications B 6 - 37 be lowered because the present limits for lead and cadmium in this grade of zinc are the same as the maximum amounts of these elements that can be tolerated in the zinc die-casting alloys. This recommendation was made for two reasons: namely, (*1*) because even under the best conditions some lead or cadmium may be picked up in the alloying or die-casting operations, and (*2*) because it is not desirable to have the same impurity limits for both the finished product and the raw material. Inasmuch as the limits for lead and cadmium have been found by tests to be the maximum safe limits for die castings, a spread in impurity limits between the raw material and the finished product can only be attained by lowering the limits for these elements in the specifications for special high grade zinc.

Subcommittee V on Exposure and Corrosion Tests (W. M. Peirce, chairman) recalled all of the zinc and aluminum alloy test bars that were still being either outdoor or indoor aged from those exposed in 1929, and the zinc and magnesium alloy test bars, scheduled to be returned at the end of five years, from those exposed in 1939. Specimens in both cases were located in six outdoor and four indoor locations, although all of those at the outdoor location in Rochester, N. Y., were destroyed some time ago without the committee's knowledge. In addition, the committee also recalled twenty round and four flat tension bars of each of two special purity aluminum and one standard aluminum alloys from three outdoor locations after ten years of exposure.

The services of twenty laboratories were secured for the testing of the above specimens. Mechanical property data for most of the specimens have already been received.

Subcommittee VII on Magnesium-Base Die Casting Alloys (H. W. Schmidt, chairman) approved editorial revisions in Emergency Specifications ES - 40 consisting of changing the title to read "Special Quality Magnesium-Base Alloy Die Castings" and referring to the product in the text of the specifications as "special quality die castings."

Subcommittee VIII on Copper-Base (Brass) Die Casting Alloys (J. C. Fox, chairman) reported some of the mechanical properties that were obtained on brass alloy die castings made by several producers from alloys both with the normal range of compositions as well as from alloys having the maximum and minimum impurity limits.

This report has been submitted to letter ballot of the committee which consists of 82 members; 62 members returned their ballots, of whom 56 have voted affirmatively, and 1 negatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

G. L. WERLEY,
Secretary.

EDITORIAL NOTE

On June 27, 1945, the Administrative Committee on Standards accepted the recommendation of Committee B-6 that the following specifications be continued in their present form:

Tentative Specifications for:

Copper-Base (Brass) Alloy Die Castings (B 176 – 42 T),
Special Quality Zinc-Base Alloy Die Castings (B 186 – 42 T),

Emergency Specifications for:

Special Quality Aluminum-Base Alloy Die Castings (ES – 29), and
Special Quality Magnesium-Base Alloy Die Castings (ES – 40).

REPORT OF COMMITTEE B-7
ON
LIGHT METALS AND ALLOYS, CAST AND WROUGHT*

During the past year, Committee B-7 on Light Metals and Alloys, Cast and Wrought, held no meetings, partly because of Government restrictions and partly because the specifications under the jurisdiction of the committee were reviewed completely last year. The Advisory Committee of Committee B-7, however, acted on a number of routine matters by correspondence and met in Pittsburgh, Pa., on April 12, to review the activities of the subcommittees, to elect a new vice-chairman, and to discuss the future work of the committee.

Changes in membership of the committee, approved by the Advisory Committee, have increased the total to 60; of whom 27 are producers, 23 consumers, and 10 general interest members. R. W. Waring, vice-chairman of Committee B-7 and chairman of Subcommittee II, resigned because of change in employment. The Advisory Committee elected Walter Bonsack to serve as vice-chairman, and I. V. Williams was appointed as chairman of Subcommittee II.

Subsequent to the 1944 Annual Meeting, Committee B-7 presented to the Society through Committee E-10 on Standards the following recommendations:

Revision of Tentative Specifications for:
Aluminum-Base Alloys in Ingot Form for Sand Castings (B 58 - 42 T),
Aluminum-Base Alloys in Ingot Form for Permanent Mold Castings (B 112 - 41 T), and
Aluminum-Base Alloys in Ingot Form for Die Castings (B 125 - 42 T).

The first two recommendations were accepted[1] by Committee E-10 on November 9, 1944, and the latter on November 13, 1944. The revised tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part I.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is submitting one proposed new tentative specification and is recommending revisions in five tentative specifications,[2] the adoption as standard of three tentative methods, the continuation of a tentative specification as tentative, and the revision of a standard for immediate adoption. The standard and tentatives affected are listed in Table I and the revisions recommended are given in detail in Appendix I.

These recommendations have been submitted to letter ballot of the committee which consists of 60 members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum and Aluminum Alloy Ingots (A. Sugar, chairman).—Following the 1944 Annual Meeting, the subcommittee recommended revisions in Tentative Specifications B 58 and B 112 which, as mentioned above, were accepted by Committee E-10 in November, 1944. The subcommittee also was responsible for the revisions in Tentative Specifications B 125 which changes had been made to bring the specifications in line with the revisions made in the Tentative Specifications for Aluminum-Base Alloy Die Castings (B 85 – 44 T)[3] on the recommendation of Committee B-6 on Die-Cast Metals and Alloys.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting these recommendations to Committee E-10 on Standards, Committee B-7 reported the following results of the letter ballot vote from a committee membership of 57: B 58, affirmative 24, negative 1, ballots marked "not voting" 8; B 112, affirmative 24, negative 0, ballots marked "not voting" 9; B 125, affirmative 27, negative 1, ballots marked "not voting" 7.

[2] These specifications were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I. See Editorial Note, p. 140.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE SPECIFICATIONS			
Spec. for Magnesium-Base Alloy Permanent Mold Castings	31	0	7
II. REVISION OF TENTATIVES			
Spec. for Magnesium-Base Alloy Sand Castings (B 80 – 44 T)	32	0	6
Spec. for Magnesium-Base Alloy Sheet (B 90 – 44 T)	28	0	10
Spec. for Magnesium-Base Alloy Forgings (B 91 – 44 T)	27	0	11
Spec. for Magnesium-Base Alloys in Ingot Form for Sand Castings and Die Castings (B 93 – 44 T)	32	0	6
Spec. for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 44 T)	31	0	7
III. ADOPTION OF TENTATIVES AS STANDARD			
Test for Sealing of Anodically Coated Aluminum (B 136 – 40 T)	29	0	9
Test for Weight of Coating on Anodically Coated Aluminum (B 137 – 40 T)	29	0	9
Test for Dielectric Strength of Anodized Aluminum (B 110 – 39 T), with change in title	29	0	9
IV. REVISION OF STANDARD, IMMEDIATE ADOPTION			
Spec. for Magnesium Ingot and Stick for Remelting (B 92 – 41)	29	0	9
V. TENTATIVE SPECIFICATIONS CONTINUED AS TENTATIVE			
Spec. for Aluminum for Use in Iron and Steel Manufacture (B 37 – 42 T)	31	0	7

Subcommittee III on Wrought Aluminum and Wrought Aluminum Alloys (P. V. Faragher, chairman).—The wrought alloy specifications under the jurisdiction of this subcommittee have become well established and crystallized during the war. No meetings of the subcommittee were held and no changes in specifications were requested. The subcommittee has been inactive, but it is believed, however, that post-war consumer interest in aluminum will necessitate greater activity with respect to specifications for wrought aluminum products.

Subcommittee IV on Magnesium and Magnesium Alloys, Cast and Wrought (H. W. Schmidt, chairman).—Magnesium-base alloy permanent mold castings are becoming increasingly important, with the result that the committee was requested to prepare specifications covering them. The committee has accordingly completed the proposed Tentative Specifications for Magnesium-Base Alloy Permanent Mold Castings,[2] which are recommended for publication as tentative.

In view of changes in commercial practices and in the corresponding Government specifications for the products covered, the subcommittee prepared revisions, as covered in Appendix I in the following tentative specifications which are being submitted at this time:

Tentative Specifications for:[3]

Magnesium-Base Alloy Sand Castings (B 80 – 44 T),
Magnesium-Base Alloy Sheet (B 90 – 44 T),
Magnesium-Base Alloy Forgings (B 91 – 44 T),
Magnesium-Base Alloys in Ingot Form for Sand Castings and Die Castings (B 93 – 44 T), and
Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 44 T).

Inasmuch as the composition limits now forming a part of the Standard Specifications for Magnesium Ingot and Stick for Remelting (B 92 – 41) do not reflect current commercial practice and do not secure for the consumer the quality of material needed, the revisions listed in Appendix I are being recommended for immediate incorporation in the standard.

The subcommittee is cooperating with Subcommittee VIII of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys in the development of a program for the atmospheric exposure of galvanic couples of magnesium with other metals. This program is now completed and the preparation of specimens will soon be taken in hand.

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[3] 1944 Book of A.S.T.M. Standards, Part I.

Subcommittee V on Testing of Light Alloys (R. L. Templin, chairman).—The subcommittee held no meetings during the year because no problem concerning mechanical testing pertinent to the specifications coming under the jurisdiction of Committee B-7 were referred to the subcommittee.

Changes in the Standard Methods of Tension Testing of Metallic Materials (E 8 – 42)[3] now being considered, if adopted, will probably affect dimensions of test bars used in some of the specifications under the jurisdiction of Committee B-7. No action will be taken by Subcommittee V, however, until these changes are adopted.

Recently certain questions with respect to the measurement of elongation of low-ductility alloys have been brought to the attention of Subcommittee V and it is hoped that some experimental work can be sponsored by the subcommittee which will lead to satisfactory answers to the problems presented.

Subcommittee VI on Anodic Oxidation of Aluminum and Aluminum Alloys (J. D. Edwards, chairman).—For several years, Subcommittee VI has been conducting an investigation comparing the performance of anodic coatings in salt spray and in weather exposure at various locations. The salt spray tests were completed and the results reported in connection with the 1943 report of Committee B-7.[4] In that report, some preliminary information was given on the performance of the test coatings outdoors. These weather exposures have been continued for approximately three years, and it was decided to make a final examination and complete the report on this investigation. This has been done and the results are presented in Appendix II to this report.

In accordance with the recommendation of the subcommittee, the Tentative Methods of Test for Sealing of Anodically Coated Aluminum (B 136 – 40 T),[3] for Weight of Coating on Anodically Coated Aluminum (B 137 – 40 T),[3] and for Dielectric Strength of Anodized Aluminum (B 110 – 39 T)[3] are recommended for adoption as standard without revision with the exception of the title of Method B 110 which it is recommended be changed to read "Standard Method of Test for Dielectric Strength of Anodically Coated Aluminum."

Subcommittee VII on Codification of Light Alloys (I. V. Williams, chairman).—A code system was developed several years ago to designate all of the aluminum alloys covered by A.S.T.M. specifications. This code system has now been incorporated into the specifications under the jurisdiction of Committee B-7 and Committee B-6 on Die-Cast Metals and Alloys. The basis of this code system is as follows:

> One or two letters are used to indicate the major alloying element present. If there is only one major alloy, only one letter is used. If there are two major alloying elements present, two letters are used. If the numbers following the letters are below 20, it indicates that only those elements designated by the code letters are present in the alloy. If the number is between 20 and 40, it indicates that there is one alloying element present other than those indicated by the code letters. If the number is over 40, it indicates that there are two or more alloying elements present other than those indicated by the code letters. Only those elements for which a minimum percentage is shown are used as a basis for the code designation.

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[4] J. D. Edwards, "A Comparison of the Performance of Anodic Coatings on Wrought Aluminum Alloys When Exposed to Salt Spray and to the Weather," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 182 (1943).

The code letters which have been used are as follows:

C—Copper
S—Silicon
G—Magnesium
N—Nickel
A—Aluminum
M—Manganese
R—Chromium
Z—Zinc

The alloys in any group will be numbered in sequence as they are accepted for inclusion in A.S.T.M. standards. In setting up the code, the alloys containing the smallest amount of alloying elements or impurities were given the lowest numbers; however, this method cannot always be followed as new alloys are added since it is not planned to change the numbers of existing alloys.

This report has been submitted to letter ballot of the committee, which consists of 60 members; 38 members returned their ballots, of whom 37 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

D. L. COLWELL,
Chairman.

J. J. BOWMAN,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 5, a number of recommendations affecting tentatives referred to in the report were submitted by Committee B-7 and accepted by the Administrative Committee on Standards on June 27, 1945. The revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR LIGHT METALS AND ALLOYS, CAST AND WROUGHT

I. New Tentative Specifications

Tentative Specifications for Magnesium-Base Alloy Permanent Mold Castings[1]

The committee recommends that these specifications be accepted for publication as tentative.

II. Revisions of Tentative Standards

The committee recommends that the following five tentative specifications be revised as indicated below and continued as tentative.

Tentative Specifications for Magnesium-Base Alloy Sand Castings (B 80 – 44 T):

In order to include an alloy which is finding increasing use in pressure-tight castings or where sound castings are required, add a new alloy A8 (formerly designated alloy No. 1). Accordingly, make the following revisions:

Section 1.—Change the second sentence to read as follows: "Seven types of alloys are specified and are designated alloys Nos. A8, A10, A12, ... "

Table I.—Add to the present table the chemical requirements for new alloy A8 (including A8X) as prescribed in the accompanying Table I.

Change the nickel content for all grades except AZ63X and AZ92X from "0.03" to read "0.01" max. per cent. This change is made to bring these alloys in line with Government specifications.

Table II.—Add to the present table the tensile requirements for new alloy A8 (including A8X) as prescribed in the accompanying Table II.

Explanatory Notes.—Add an explanatory note covering alloy A8 to read as follows: "*Alloy A8*.—This alloy has a specific gravity of about 1.80. It is used in the as-cast, heat-treated, and heat-treated-and-aged conditions. This alloy will produce castings having the maximum soundness with moderate mechanical properties."

Include alloy A8X in the Explanatory Note covering alloys AZ63X and AZ92X, making the heading read "Alloys A8X, AZ63X, and AZ92X."

Revise the second sentence of the explanatory note for alloy AZ92 to read as follows: "It is used where good soundness and mechanical properties are required."

In the explanatory notes for alloys A10, A12, AZ63, M1, AZ101, and AZ92 delete the sentence reading as follows: "The copper and nickel contents should be kept low to minimize corrosion."

Add to Table III the following values for alloys A8 and A8X:[2]

Alloy	Condition	Typical or Minimum	Yield Strength (0.2 per cent offset), min., psi.	Unit Deformation, inch per inch of gage length
A8 and A8X	Heat treated and aged	minimum	12 000	0.0038

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[1] These specifications were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Tentative Specifications for Magnesium-Base Alloy Sheet (B 90 – 44 T):

Since it is questionable if alloys AZ61 and AZ31 will again be produced commercially, delete all references to these alloys in these specifications.

Alloy AZ61X will be continued for another year. However, at that time it will be replaced by a new alloy AZ51X (to be included in these specifications at this time) which has been approved by the armed forces for aeronautical use. The new alloy has increased toughness, cold formability, and equally good welding characteristics. The minimum mechanical properties are the same as for alloy AZ61X. All of the sheet producers will be manufacturing this alloy in place of alloy AZ61X. It is suggested, therefore, that the new alloy AZ51X be included in these specifications in order that they agree with the Government specification.

TABLE I.—CHEMICAL REQUIREMENTS.

Alloy	Magnesium, per cent	Aluminum, per cent	Manganese, min., per cent	Zinc, max., per cent	Silicon, max., per cent	Copper, max., per cent	Nickel, max., per cent	Iron, max., per cent	Other Impurities, max., per cent
A8.....	remainder	7.8 to 9.2	0.15	0.3	0.3	0.05	0.01	....	0.3
A8X...	remainder	7.8 to 9.2	0.15	0.3	0.3	0.05	0.005	0.005	0.3

TABLE II.—TENSILE REQUIREMENTS.

Alloy	Condition	Tensile Strength, min., psi.	Yield Strength (0.2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
A8 and A8X...	As cast...........	23 000	....	3
	Heat treated......	32 000	....	7
	Heat treated and aged...........	32 000	12 000	4

In order that alloy M1 agree with the Government specification, it is proposed to limit the nickel content of this alloy. The change would not affect any manufacturer since all sheet is now made to the lower limit.

TABLE IV.—TENSILE REQUIREMENTS.

Alloy	Condition	Tensile Strength, min., psi.	Yield Strength (0.2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
AZ31X....	Hard rolled (H)........	39 000 min.	29 000	4
	Annealed (A)	40 000 max.[a]	......	12
AZ51X and AZ61X..	Hard rolled (H)........	42 000 min.	30 000	3
	Annealed (A)	46 000 max.[a]	......	8
M1........	Hard rolled (H)........	32 000 min.	22 000	3
	Annealed (A)	38 000 max.[a]	......	12

[a] To insure complete annealing.

In accordance with the above, make the following changes:

Section 1.—Change editorially the second sentence to read as follows: "Four types of alloys are specified and are designated alloys AZ31X, AZ51X, AZ61X, and M1 (see Explanatory Note 1)."

Table I.—Replace the present table on chemical requirements with the accompanying Table III.

Table II.—Replace the present table on tensile requirements with the accompanying Table IV.

Section 6.—Revise to read as follows:

TABLE III.—CHEMICAL REQUIREMENTS.

Alloy	Magnesium, per cent	Aluminum, per cent	Manganese, min., per cent	Zinc, per cent	Silicon, max., per cent	Copper, max., per cent	Nickel, max., per cent	Iron, max., per cent	Calcium, max., per cent	Other Impurities, max., per cent
AZ31X..........	remainder	2.5 to 3.5	0.20	0.6 to 1.4	0.3	0.05	0.005	0.005	0.3	0.3
AZ51X..........	remainder	4.1 to 5.5	0.15	0.4 to 1.3	0.3	0.05	0.005	0.005	0.3	0.3
M1..............	remainder	......	1.20	......	0.3	0.05	0.01	....	0.3	0.3
AZ61X..........	remainder	5.8 to 7.2	0.15	0.4 to 1.5	0.3	0.05	0.005	0.005	0.3	0.3

"The tension test specimens shall be cut in the direction of rolling or longitudinal direction and shall be machined to the form and dimensions shown in Fig. 1."

Explanatory Notes.—Delete Note 1 and substitute the following:

NOTE 1.—The resistance to salt water corrosion of the X grade alloys is substantially the same and superior to alloy M1. All of the alloys have a specific gravity of about 1.8.

Alloy M1.—This alloy has the best rolling characteristics. It is used where weldability and hot forming are primary considerations.

Alloy AZ31X.—In the annealed condition this alloy has the best cold formability and toughness. In the hard-rolled condition this alloy has substantially the same strength as alloy AZ51X but with improved toughness. It is the general purpose high-strength alloy.

Alloy AZ51X.—This alloy is used where strength and weldability are the primary factors. This alloy is replacing Alloy AZ61X.

Alloy AZ61X.—This alloy has the same strength as alloy AZ51X but somewhat less toughness. It is being replaced by Alloy AZ51X.

NOTE 2.—In Table III, delete in the first column reference to alloys AZ31 and AZ61, and add the following values for alloy AZ51X:

Alloy	Yield Strength (0.2 per cent, off-set), min., psi	Unit Deformation, inch per inch of gage length
AZ51X	30 000	0.0066

Tentative Specifications for Magnesium-Base Alloy Forgings (B 91 – 44 T):

Since it is questionable if alloys AZ61, AZ80, and AZ31 will again be produced commercially and since alloys AZ33 and AZ33X are obsolete, delete these five alloys from these specifications. Accordingly, make the following revisions:

Section 1.—Change editorially the second sentence to read as follows: "Four types of alloys are specified and are designated alloys AT35, AZ31X, AZ61X, and AZ80X (see Explanatory Note 2)."

Table I.—Delete all requirements for alloys AZ61, AZ80, AZ33, AZ33X, and AZ31 from the present table on chemical requirements including reference to them in footnote *a* at the foot of the table.

Table II.—Replace the present table on tensile requirements with the accompanying Table V. The aged condition has been added to alloy AZ80X as this condition gives the highest strength of any of the forging alloys. The compression yield strength is particularly good in this condition.

Section 6.—At the end of the first sentence, delete the phrase "and where practicable shall be taken from a full sized prolongation of the forging." This practice comes from aluminum propeller forgings and is never used with magnesium forgings.

Explanatory Notes.—Delete Note 2 in its entirety and substitute the following:

NOTE 2.—The resistance to salt water corrosion of all of the X grade alloys is substantially the same and superior to alloy AT35. The iron and nickel are controlled to low limits.

TABLE V.—TENSILE REQUIREMENTS.

Alloy	Tensile Strength, min., psi.	Yield Strength[a] (0.2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
AZ31X	34 000	19 000	6.0
AZ61X	38 000	22 000	6.0
AZ80X	42 000	26 000	5.0
AZ80X (aged)	42 000	28 000	2.0
AT35	36 000	22 000	7.0

[a] See Explanatory Note 3.

TABLE VI.—CHEMICAL REQUIREMENTS.

Alloy	Magnesium, per cent	Aluminum, per cent	Manganese, min., per cent	Zinc, max., per cent	Silicon, max., per cent	Copper, max., per cent	Nickel, max., per cent	Iron, max., per cent	Other Impurities, max., per cent
A8	remainder	8.0 to 9.0	0.18	0.20	0.2	0.04	0.01	....	0.3
A8X	remainder	8.0 to 9.0	0.18	0.20	0.2	0.04	0.003	0.003	0.3

Alloy AZ31X.—This alloy has a specific gravity of about 1.77. It has better press forging characteristics than any of the other alloys and may be worked on mechanical presses.

Alloy AZ61X.—This alloy has a specific gravity of about 1.81. The forgeability and mechanical properties are intermediate between those of alloy AZ31X and AZ80X.

Alloy AZ80X.—This alloy has a specific gravity of about 1.83. It is used for hot press forgings of relatively simple design requiring maximum mechanical properties.

Alloy AT35.—This alloy has a specific gravity of about 1.87. It is the best hammer forging alloy.

Table III.—Replace the present Table III with the following table:

Alloy	Yield Strength (0.2 per cent offset), min., psi.	Unit Deformation, inch per inch of gage length
AT35	22 000	0.0054
AZ31X	19 000	0.0049
AZ61X	22 000	0.0054
AZ80X	26 000	0.0060
AZ80X (aged)	28 000	0.0063

Tentative Specifications for Magnesium-Base Alloys in Ingot Form for Sand Castings and Die-Castings (B 93 – 44 T):

Section 1.—Change the third sentence to read as follows: "Nine types of alloys are specified and are designated alloys Nos. A8, A10, A12, ..."

Table I.—Add to the present table the chemical requirements for new alloy A8 (including A8X as prescribed in the accompanying Table VI).

In order to allow this ingot to be used for making castings in accordance with Government specifications, change the requirements for nickel for alloys Nos. A10, A12, AZ63, M1, AS100, AZ90, AZ101, and AZ92 from "0.02" to read "0.01" max., per cent.

Tentative Specifications for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 44 T):

As recommended above in Specifications B 91 – 44 T, delete the five alloys mentioned, and accordingly make the following revisions:

Section 1.—Change editorially the second sentence to read as follows: "Four types of alloys are specified and are designated alloys AZ31X, AZ61X, AZ80X, and M1 (see Explanatory Note 1)."

Table I.—Delete all requirements for alloys AZ61, AZ80, AZ33, AZ33X, and AZ31 from the present table on chemical requirements including reference to them in footnote *a* at the foot of the table.

Change the requirement for zinc in alloy AZ31X from "0.7 to 1.3" to read "0.6 to 1.4" per cent.

Change the requirement for nickel in alloy M1 from "0.03" to read "0.01" max., per cent.

Add a new column to the table (before the last column) with a heading to read as follows: "Calcium, max., per cent" and a requirement for alloy M1 only, to read "0.3."

The above changes are in accordance with Government specifications and commercial production.

Table II.—Replace the present table on tensile requirements with the accompanying Table VII.

Explanatory Notes.—Delete Note 1 in its entirety and substitute the following:

TABLE VII.—TENSILE REQUIREMENTS.

Alloy	Shape and Size	Tensile Strength, min., psi.	Yield Strength (0.2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
AZ31X	Round and square up to 1½ in.	35 000	22 000	10
	Structural shapes	34 000	20 000	10
AZ61X	Round and square up to 1½ in.	40 000	26 000	11
	Structural shapes	40 000	22 000	10
AZ80X	Round and square up to 1½ in.	43 000	28 000	9
	Structural shapes	40 000	25 000	5
AZ80X (aged)	Round and square up to 1½ in.	45 000	30 000	5
	Structural shapes	44 000	27 000	4
AZ80X (heat treated and aged)	Round and square up to 1½ in.	48 000	33 000	4
	Structural shapes	47 000	30 000	5
M1	Round and square up to 1½ in.	30 000	.....	3
	Structural shapes	29 000	.....	2

NOTE 1.—The resistance to salt water corrosion of the **X** grade alloys is substantially the same and superior to alloy M1. All the alloys have a specific gravity of about 1.8.

Alloy M1.—This alloy has the best extrusion characteristics.

Alloy AZ31X.—This alloy has good extrusion characteristics and moderate mechanical properties.

Alloy AZ61X.—This alloy has extrusion characteristics and mechanical properties intermediate between alloys AZ31X and AZ80X.

Alloy AZ80X.—In the heat-treated and aged condition this alloy has the highest mechanical properties of any of the extrusion alloys.

Table III.—Replace the present Table III with the following table:

Alloy	Shape and Size	Yield Strength (0.2 per cent offset), min., psi.	Unit Deformation, inch per inch of gage length
AX31X	Round and square up to 1½ in.	22 000	0.0054
	Structural shapes	20 000	0.0051
AZ61X	Round and square up to 1½ in.	26 000	0.0060
	Structural shapes	22 000	0.0054
AZ80X	Round and square up to 1½ in.	28 000	0.0063
	Structural shapes	25 000	0.0058
AZ80 (aged)	Round and square up to 1½ in.	30 000	0.0066
	Structural shapes	27 000	0.0062
AZ80X (heat treated and aged)	Round and square up to 1½ in.	33 000	0.0071
	Structural shapes	30 000	0.0066

III. REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends that the following standard specifications be revised as indicated below and continued as standard.

Standard Specifications for Magnesium Ingot and Stick for Remelting (B 92 – 41):

Section 3.—Revise the table in this section to agree with the following:

Total of aluminum, copper, iron, manganese, nickel, and silicon, max., per cent	0.20
Copper, max., per cent	0.02
Nickel, max., per cent	0.001
Magnesium, by difference, min., per cent	99.80

This change is being made to bring these specifications in line with commercial production and to insure that this ingot can be used to make the various magnesium wrought products described in A.S.T.M. Specifications B 90 – 44 T, B 91 – 44 T, B 107 – 44 T, etc., as the X grade of alloys. The product specifications noted above limit the nickel content to 0.005 max. per cent.

APPENDIX II

A COMPARISON OF THE PERFORMANCE OF ANODIC COATINGS EXPOSED TO SALT SPRAY AND TO THE WEATHER

PREPARED BY JUNIUS D. EDWARDS[1]

In 1941, Subcommittee VI on Anodic Oxidation of Aluminum and Aluminum Alloys of Committee B-7 inaugurated a series of tests to evaluate the salt spray test as a measure of the protective quality of anodic coatings. For this test, two different aluminum alloys were selected and given a variety of anodic coatings. The series comprised eight different test specimens and sufficient samples were anodically coated to supply the six cooperating laboratories. Salt spray tests were conducted in four laboratories and weather-exposure tests by five. A preliminary report giving the results of the salt spray test was presented in 1943.[2] The parallel weather exposure tests have proceeded to such an extent that a final report can now be prepared.

The results of the salt spray tests are summarized in Table I, which also includes a description of the panels. In the salt spray test as conducted by three laboratories, none of panels Nos. 2 to 7, inclusive, showed any failure in the first 700 hr. of exposure to salt spray. Panels Nos. 8 and 9 began to show attack in the period of 200 to 700 hr. of salt spray exposure. In fact, some of the panels showed no failure after 6 months' exposure to salt spray. A 700-hr. exposure period is about as long as is practical for an accelerated test. In fact, it is usually too long for an acceptance test.

The panels exposed to the weather varied greatly in appearance, depending on the particular panel and place and period of exposure. This difference in appearance was largely due to variations in the amount of dirt accumulated on the panels. The manner of failure of the coating was usually a breakdown of the oxide at points, followed by a small accumulation of corrosion products. This resulted in some roughening of the surface, and this roughness greatly facilitated the accumulation of dust and soot. In some cases this embedded dirt was so adherent that it was not readily removed with soap and water, which was the method of cleaning specified in the test program.

The method finally decided upon for evaluating the condition of the panels was to rate them in order with regard to freedom from corrosive attack. The best panel in each series exposed in a particular location was rated No. 1 and the panel showing most attack was rated No. 8. These ratings are purely relative and are not quantitative. For example, the condition of a panel rated No. 5 in one series may differ appreciably from another panel rated No. 5 after exposure at another location. Some of the panels were not available for examination by the author, and their relative rating had to be based on an interpretation of a report from the laboratory making the exposure.

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[1] Assistant Director of Research, Aluminum Company of America, New Kensington, Pa.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 182 (1943).

TABLE I.—DESCRIPTION OF TEST PANELS AND RESULTS OF SALT SPRAY TESTS.

Specimen	Alloy Coated	Electrolyte	Sealing Procedure	Time of Coating, min.	Thickness of Coating, in.	Laboratory Reports First Attack in Salt Spray, hr.[a]		
						Laboratory A	Laboratory B	Laboratory C
No. 2	52S	Sulfuric acid	Hot water	20	0.00028	None*	None†	None‡
No. 3	52S	Sulfuric acid	Hot water	30	0.00039	None*	None†	None‡
No. 4	52S	Sulfuric acid	Dichromate	10	0.00012	None*	1100	None‡
No. 5	52S	Sulfuric acid	Dichromate	20	0.00029	None*	None†	None‡
No. 6	52S	Sulfuric acid	Dichromate	30	0.00037	None*	None†	None‡
No. 7	17S-T	Sulfuric acid	Dichromate	30	0.00041	None*	None†	None‡
No. 8	17S-T	Chromic acid	No seal	30	0.00005	600	200	200
No. 9	17S-T	Sulfuric acid	Hot water	30	0.00033	600	700	200

[a] The rating "none" includes those panels showing only a few small pinhole points of attack.
* After 6 months' exposure.
† After 2100 hr. (about three months) exposure.
‡ After 700 hr. exposure.

TABLE II.—RELATIVE ATTACK ON PANELS AS OBSERVED AFTER CLEANING.[a]

Panel	Laboratory A		Laboratory B		Laboratory C		Laboratory E		Summary Order Number of Panels Front and Back
	Front	Back	Front	Back	Front	Back	Front	Back	
No. 2	6	2	6	3	5	4	6	3	5 or 6
No. 3	3	2	4	2	4	2	5	2	2
No. 4	7	5	8	7	7	5	7	7	7
No. 5	3	2	7	3	6	3	4	3	3
No. 6	1	1	3	1	2	1	3	1	1
No. 7	5	6	2	5	2	7	2	6	6 or 5
No. 8	8	8	5	8	8	8	8	8	8
No. 9	3	7	2	6	2	6	1	5	4

[a] Laboratory A—New Kensington exposure, 42 months.
Laboratory B—Philadelphia exposure, 42 months.
Laboratory C—New York exposure, 36 months.
Laboratory E—Chicago exposure, 45 months.

surface with soot and dust interfered with a precise determination of the degree of attack, the panels from four exposure stations, which were available, were cleaned front and back on half of the surface. This cleaning was done by rubbing with cheesecloth, warm water and a mild abrasive cleaner. After this cleaning, another comparison was made of all of these panels by R. B. Mears and the author. The results of this examination are given in Table II. This method of rating is not without objection, but the net result seems reliable and the method is very helpful in presenting a word picture of the test. Similar ratings based on the examination before cleaning (referred to in the previous paragraph) are in general agreement with those presented in Table II.

It is obvious from an examination of the test panels that the character of the exposure differed at the different locations. All of these locations are what might be described as "industrial." The Philadelphia exposure, however, seemed to be the most severe. The New York and New Kensington exposures produced the least attack, while that of Chicago was intermediate. The degree of attack seemed to be connected with the amount of dirt accumulated on the panels. The two effects are not independent, but general experience seems to indicate that breakdown of the coating may eventually result at points where moist soot or dirt have remained in contact with the coating for extended periods. The pitting and dirt accumulation are worst on the backs of the panels since the backs are not freely washed by rain and remain moist the longest.

In comparing the ratings in Table II with the characteristics of the coatings, the conclusion seems warranted that resistance to attack increases with thickness of coating, and that the dichromate-sealing procedure lends somewhat greater resistance than the water-sealing procedure. Coatings on 52S alloy show less attack than equivalent coatings on 17S-T.

The principal objective of these experiments was to determine to what extent the salt spray test would predict the behavior of anodic coatings under service conditions. The results indicate that a coating which shows early failure during exposure to salt spray will show low durability on outdoor exposure. Panel No. 8 showed the poorest performance both in salt spray and in weather exposure. Panel No. 9, which was one of the first two panels to fail in the salt spray test, was given a rating of 4 in the weather exposure test. However, in a marine exposure (not included in Table II), panel No. 9 was given a rating of 7 after 31 months' exposure; this behavior is in better agreement with the salt spray tests. Panel No. 4 was among the two poorest panels in the weather-exposure test, but did quite well—up to 700 hr.—in the salt spray test. On continued exposure to salt spray, however, it eventually broke down. It would appear that thickness of coating is a more important consideration in a long period of weather exposure than in a short salt spray test.

One of the extensive uses of anodic coatings is as surface preparation for painting. In this type of service, the coating is not directly exposed to the weather, so that weather-exposure tests are not necessarily a measure of the serviceability of a coating as a base for paint.

The general conclusion to be drawn from these tests is that early failure in salt spray indicates a coating of inferior protective quality. However, because of differences in the characteristics of the coatings themselves and in service conditions, only an approximate correlation can be expected between the weather-exposure test and the salt spray test in the case of the more resistant coatings such as show little or no attack in the first few hundred hours of the salt spray test.

REPORT OF COMMITTEE B-8

ON

ELECTRODEPOSITED METALLIC COATINGS*

Committee B-8 on Electrodeposited Metallic Coatings held one meeting during the year, on June 28, 1944, in New York, N. Y.

A meeting of the Advisory Committee was held in Pittsburgh, Pa., on March 2, 1945, in place of the regular meeting of the committee which was cancelled when the Spring group meetings of the Society were cancelled.

The membership of the committee now totals 87, of whom 33 are classified as producers, 10 as consumers, 43 as general interest members, and 1 consulting member.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is submitting two proposed new tentatives, one of which had formerly been issued as an emergency standard, and is recommending revisions in four tentatives[1] and the adoption as standard of a revised tentative, as referred to under the activities of subcommittees. The tentatives affected are listed in Table I and the revisions recommended are given in detail in the Appendix.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 74 voting members with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE SPECIFICATIONS			
Spec. for Electrodeposited Coatings of Lead on Steel (formerly issued as Emergency Specifications ES - 31)	44	0	16
Spec. for Chromate Finishes on Electrodeposited Zinc Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces	50	0	10
II. REVISION OF TENTATIVES			
Spec. for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 41 T)	47	2	11
Spec. for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 - 41 T)	49	0	11
Test for Local Thickness of Electrodeposited Coatings (A 219 - 40 T)	56	0	4
Rec. Practice for Chromium Plating on Steel for Engineering Use (B 177 - 43 T)	49	0	11
III. ADOPTION OF TENTATIVE SPECIFICATIONS AS STANDARD			
Spec. for Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 - 41 T), as revised	50	0	10
IV. TENTATIVE RECOMMENDED PRACTICE CONTINUED AS TENTATIVE			
Rec. Practice for Preparation of Low-Carbon Steel for Electroplating (B 183 - 43 T)	52	0	8

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Specifications (K. G. Soderberg, chairman) has reviewed the specifications under its jurisdiction and recommends that the Emergency Specifications for Electrodeposited Coatings of Lead on Steel (ES - 31), revised as appended hereto,[2] be accepted for publication as tentative.[1] It recommends further that the Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 – 41 T)[3] be revised and approved for reference to letter ballot of the Society for adoption as standard, and that the following tentatives be revised as indicated in the Appendix and continued as tentative:

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] See Editorial Note, p. 150.

[2] These specifications and methods were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Tentative Specifications for:

Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 – 41 T),
Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 – 41 T),
Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A 219 – 40 T), revised as appended hereto,[2] and
Tentative Recommended Practice for Chromium Plating on Steel for Engineering Use (B 177 – 43 T)

It is recommended that the Tentative Recommended Practice for Preparation of Low-Carbon Steel for Electroplating (B 183 – 43 T)[3] be continued as tentative without revision.

Subcommittee II on Performance Tests (H. A. Pray, chairman) has continued the atmospheric exposure tests on electrodeposited lead coatings on steel. The results of inspections to date are summarized in the report of this subcommittee which is appended hereto.

The subcommittee has also completed preliminary work relative to a series of atmospheric exposure tests on electroplated coatings of copper-nickel-chromium on high-carbon steel of bumper-bar grade.

Subcommittee III on Conformance Tests (C. H. Sample, chairman) reviewed the paper by Samuel Lipson on "A New Coating Thickness Gage,"[4] and recommended that the committee sponsor presentation of the paper to the Society.

Subcommittee V on Supplementary Finishes for Metallic Coatings (L. G. Tubbs, chairman) prepared the Specifications for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces[2] which are recommended for publication as tentative.

This report has been submitted to letter ballot of the committee which consists of 74 voting members; 60 members returned their ballots, of whom 58 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

R. J. McKAY,
Chairman.

C. H. SAMPLE,
Secretary.

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[3] 1944 Book of A.S.T.M. Standards, Part I.

[4] ASTM BULLETIN, No. 135, August 1945, p. 20.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-8 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Specifications for:

Electrodeposited Coatings of Lead on Steel (B 200 – 45 T) to supersede Emergency Specifications ES – 31,
Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces (B 201 – 45 T),

Revised Tentative Specifications for:

Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 – 45 T),
Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 – 45 T),

Revised Tentative Recommended Practices for:

Chromium Plating on Steel for Engineering Use (B 177 – 45 T), and

Revised Tentative Method of Test for:

Local Thickness of Electrodeposited Coatings (A 219 – 45 T), submitted jointly with Committee A-5 on Corrosion of Iron and Steel.

These recommendations were accepted by the Standards Committee on August 27, 1945, and the new and revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I, under the designations indicated above.

At the same time, the Society accepted the recommendation of the committee that the Tentative Recommended Practice for Preparation of Low-Carbon Steel for Electroplating (B 183 – 43 T) be continued as tentative without revision.

REPORT OF SUBCOMMITTEE II ON PERFORMANCE TESTS

The specimens of electroplated lead coatings on steel exposed to the atmosphere at New York, N. Y., State College, Pa., Kure Beach (Wilmington), N. C., and Tela, Honduras have been inspected at intervals during the past year. The data, in summary form, are contained in Table I (Plate IV),[1] which is supplementary to Table II of the 1944 report[2] of this subcommittee which contains a detailed outline of these exposure tests.

The original method of recording the results has undergone some modification, as can be seen from the table. The symbols "D" and "W" (darkening or whitening of the coating) have been eliminated since all of the pure lead coatings at a given location acquire the same appearance in this respect and since the lead-alloy coatings darken at all locations. The symbols "IP" (irregularly distributed pinholes, numbering more than 25) and "RP" (regularly distributed pinholes, numbering more than 25) have not been considered to represent a significant difference and have been supplanted in the more recent inspections by "MP" which signifies the existence of more than 25 pinholes. The most important change has resulted from the recognition by the inspection groups that a rust coating on the panels can be of two types: (*1*) a smooth coating, having the appearance of rust, but under which the lead coating is apparently intact and the base metal apparently undamaged, and (*2*) a rough, flaky rust coating under which the lead coating, if any, has ceased to be protective and the base metal has been visibly attacked. On this basis, the symbol "S" is being used to designate type 1 and the symbol "R" is being retained to indicate type 2.

At New York, after a total exposure of 0.87 yr. there was evidence of a small amount of white corrosion product on the upper surface which was considerably more pronounced on the under surface of the lead-coated panels and considerably less pronounced on the lead-alloy-coated specimens. During the life of the tests, the white deposit has been much heavier at State College and Kure Beach than at New York, and heavier on the upper side. At Tela, the panels are mottled, dark and white. At all stations, the alloy coatings have darkened and show little or no evidence of white corrosion product at the present stage of the tests.

From the accompanying Table I, it is evident that damage to the steel base increases progressively with exposure time and decreases with increasing coating thickness. The Kure Beach (sea coast) atmosphere appears to be the most severe on all of the lead-coating systems. The industrial atmosphere of New York is generally the least severe, although not so for all coating thicknesses and combinations. It is also apparent that the thinner lead and lead-alloy coatings have a relatively short life in all of the four types of atmosphere.

A copper flash (0.000015 in.) under the thinnest lead deposit (0.000080 in.) is detrimental or of no benefit, whereas, under the thicker plates it increases (or at least does not shorten) the period during which the coating is protective at the four stations.

The plated panels having four vertical bare strips (marked "damaged" in the table) are, at the most recent inspections, showing the first evidence of an effect at the lead-steel interface. Definite spreading of the bare area, or undercutting of the lead, was noted at Kure Beach after 0.81-yr. exposure. It was less pronounced on panels carrying a copper undercoat and it decreased in severity with increased coating thickness. Spreading was also observed to a lesser degree on the "damaged" panels at State College and was not evident on those at New York and Tela at the present stage of exposure.

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[1] This plate appears in envelope on inside back cover.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p 280 (1944).

It should be emphasized that all of the above is based on the behavior of the coatings during relatively short exposure periods.

Respectfully submitted on behalf of the subcommittee,

H. A. PRAY,
Chairman.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR ELECTRODEPOSITED METALLIC COATINGS

In this Appendix are given the recommendations affecting certain standards covering electrodeposited metallic coatings which are referred to earlier in this report. The standards appear in their present form in the 1944 Book of A.S.T.M. Standards, Part I.

REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the following four tentative specifications be revised as indicated below and continued as tentative.

Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 – 41 T):

In line with projected use by automotive manufacturers, it has been found desirable to add a fourth type of coating to the three types now covered in these specifications. Accordingly, the following changes are recommended:

Section 1.—In line 6 change the first word of the second sentence from "Three" to read "Four." List "*Type D.S.*" as the first item of the four types of coatings.

Note 1.—Insert the letter "*D*" before the letter "*F*" in line 2.

Note 2.—Insert "type *D.S.*," before "type *F.S.*," in lines 4 and 11.

Section 2.—Since it has been found that service experience with nickel-copper-nickel systems has been less favorable than with other systems, make the following change in Section 2:

Delete the words "or intermediate" in line 9.

Also add a footnote after the second sentence to read as follows:

Careful preparation of the steel surface is necessary in order to assure good adhesion. For suitable methods see the Tentative Recommended Practice for Preparation of Low-Carbon Steel for Electroplating (A.S.T.M. Designation: B 183), 1944 Book of A.S.T.M. Standards, Part I.

Section 3.—In the table in this section add the following requirements for thickness of type *D.S.* coatings:

	Thickness of Coating, in. Type *D.S.*
Copper plus nickel, min.	0.0020[a]
Final nickel, min.	0.0010
Chromium (if required), min.	0.00001

[a] When copper is used (see Section 2) in excess of a thickness of 0.0001 in., its minimum thickness shall be 0.00075 in.

Section 4.—Add the following requirement for continuous exposure to the salt spray test:

Type *D.S.* .... 96 hr.

Section 8.—Since it is common practice to test the thickness of nickel coatings directly on steel by means of the magnetic methods it is desirable to make reference to the Tentative Methods A 219.[1] Accordingly add a new Paragraph (*c*) to Section 8 to read as follows:

(*c*) When agreed upon by the manufacturer and the purchaser, the thickness of a nickel coating directly on steel with or without the chromium coating may be determined by the magnetic method. This method and its limitations are described in an Appendix to the Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A.S.T.M. Designation: A 219).[1]

Section 9(b).—Since the revisions made in 1944 to the Tentative Method of Salt

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[1] These revised methods were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

Spray (Fog) Testing (B 117 - 44 T) contain the requirements now described in Section 9 (*b*), delete that portion of the paragraph following the reference to Method B 117.

Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A 219 - 40 T):

The proposed revisions include incorporating in these methods pertinent procedures and information formerly appearing in Emergency Specifications ES - 31 and Specifications B 177 and also include the addition of the less accurate but commonly used magnetic methods and dropping test for estimation of thickness in a form which permits their use when applicable. Since the proposed revisions to these methods are quite extensive, the proposed revised methods are appended hereto.[1]

Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 - 41 T):

Section 8.—Add a new paragraph to this section to read as follows:

> (*c*) When agreed upon by the manufacturer and the purchaser, the thickness of a nickel coating with or without the chromium coating may be determined by the magnetic method. This method and its limitations are described in an Appendix to the Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A.S.T.M. Designation: A 219).[1]

Section 9 (b).—Make the same changes in this paragraph as recommended above in Section 9 (*b*) of Specifications A 166.

Tentative Recommended Practice fo Chromium Plating on Steel for Engineering Use (B 177 - 43 T):

Since the provisions in Section 9 (*a*) are to be incorporated in Specifications A 219,[1] make the following changes in Section 9:

Section 9 (a).—Replace the entire paragraph with the following:

> 9. (*a*) *Thickness.*—The thickness of the chromium deposit is frequently not determined directly, the dimensions of the finished part being measured instead. When direct measurement of the thickness of coating is desired, it should be done in accordance with the Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A.S.T.M. Designation: A 219).[1]

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the following tentative specifications be approved for reference to letter ballot of the Society for adoption as standard, with revisions as indicated:

Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 - 41 T):

Section 7.—Add a new paragraph to this section to read as follows:

> (*c*) When agreed upon by the manufacturer and the purchaser, the thickness of a nickel coating with or without the chromium coating may be determined by the magnetic method. This method and its limitations are described in an Appendix to the Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A.S.T.M. Designation: A 219).[1]

NEW TENTATIVES

Tentative Specifications for Electrodeposited Coatings of Lead on Steel:

These specifications were originally issued in May, 1943, as Emergency Specifications ES - 31. With revisions incorporated in the specifications appended hereto[2] it is recommended that they be accepted for publication as tentative.

Tentative Specifications for Chromate Finishes on Electrodeposited Zinc:

These specifications outline the procedure for coating electrodeposited zinc surfaces with chromate finishes. It is recommended that they be accepted for publication as tentative as appended hereto.[2]

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[2] These specifications were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE C-1

ON

CEMENT*

War-time travel restrictions necessitated the cancellation of the committee's plans for a spring meeting. For the first time in more than thirty years, Committee C-1 on Cement held no meeting during the interval between consecutive annual meetings of the Society.

As the result of correspondence with members of the Advisory Committee of Committee C-1 and with the chairmen of the subcommittees, it was concluded that the current questions and proposals affecting standards under the jurisdiction of Committee C-1 should await the next regular meeting of the committee, where full and appropriate discussion could be secured. On that account, the committee is not now submitting any new tentatives, or any recommendations affecting standards. However, a proposed specification and a suggested method of test are presented for publication as information in order to promote discussion of the subjects.

The absence of recommendations affecting standards must not be interpreted as indicating that work within the committee has been discontinued. Some of the subcommittees continued their studies of current problems, and plans for additional work have been considered. This report briefly reviews the work of the subcommittees since the 1944 Annual Meeting of the Society.

The Sponsoring Committee on Portland Cement (C. E. Wuerpel, chairman), in meetings and through correspondence, has considered numerous subjects relating to standards for portland cement. These subjects include: chemical limitations, sampling, definition of portland cement, testing of air-entraining cements, manner of adding Vinsol resin during the grinding of the cement, and determination of entrained air in standard mortar. The sponsoring committee has been greatly interested in the question of limitations on sulfur trioxide content. Recent work of the Portland Cement Association has shown that the shrinkage of portland cements can be affected by varying the sulfur trioxide content, and that the amount of sulfur trioxide required to effect an optimum reduction in shrinkage of some cements, as those high in C_3A or in alkalies, is sometimes greater than the maximum now permitted for some types of cement under the Standard Specifications for Portland Cement (C 150 – 44) or the Tentative Specifications for Air-Entraining Portland Cement for Concrete Pavements (C 175 – 44 T). The increased interest in, and use of, the air-entraining cements has been accompanied by the subcommittee's study of the factors entering into the Tentative Method of Test for Air Content of Portland-Cement Mortar (C 185 – 44 T). The subcommittee has already presented recommendations to Committee C-1 concerning some of the subjects mentioned above and is continuing the study of other subjects. Although there has been no opportunity for Committee C-1 to consider the subcommittee's recommendations at a regular meeting, they are presented in Appendix I as information and to promote discussion.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

The Sponsoring Committee on Blended Cements (R. E. Roscoe, chairman) has for a long time been working on the preparation of specifications for blended cements, and has prepared and submitted to Committee C-1 Proposed Specifications for Portland Blast-Furnace Slag Cement. These specifications have not yet been acted upon by Committee C-1, but they are presented in Appendix II as information, with no official status, to solicit discussions.

New Tentative Specifications for Masonry Cement (C 91 – 44 T) were accepted[1] by Committee E-10 on Standards on August 28, 1944, on the recommendation of Committee C-1, and no changes therein or in the Standard Specifications for Masonry Cement (C 91 – 40) are recommended at this time.

The Working Committee on Methods of Chemical Analysis (W. C. Hanna, chairman) studied the Proposed Method of Chemical Analysis for Darex AEA (Air-Entraining Agent) in Portland Cement which was published as information with last year's report.[2] Five laboratories completed their part of the cooperative study. The results were promising but the method will require rewriting. Much time was devoted to the preparation of revised methods of chemical analysis of portland cement (C 114 – 44 and C 114 – 44 T). The subcommittee has planned further study of methods for the determination of TDA and titanium oxide in portland cement.

Closely related to the work of the Working Committee on Volume Change and Soundness of Portland Cement (H. F. Gonnerman, chairman) is the study by William Lerch, of the Portland Cement Association, on the effect of increased amounts of gypsum on the expansion in water and the contraction in air of mortar bars. This work is referred to earlier in this report, under the activities of the Sponsoring Committee on Portland Cement. In the earlier studies, 2 by 2 by $11\frac{1}{4}$-in. prisms were tested. Many laboratories are not prepared to use that size specimen, but most of them have equipment for 1 by 1 by $11\frac{1}{4}$-in. bars. Therefore, the possibilities of using the smaller bars for such length-change studies were explored. Eight cements, each with the three SO_3 contents used in the other physical tests, were employed for this comparison, employing the plastic mortar mix as described in the Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars (C 109 – 44). The results of the length change measurements of the specimens stored in water, when using the same cement in prisms of the two different sizes, are practically identical, indicating that either size of specimen is suitable for expansion measurements. The contractions of the two sizes of prisms during storage in air show some difference. At early ages the smaller specimens show more contraction than their companion larger specimens. At the end of three months the contractions of both sizes of prisms are almost identical. When comparing the effects of different SO_3 contents on the length changes of cement, the SO_3 content required to give the lowest contraction can be selected equally well with either size of specimen at any age.

The Working Committee on Sulfate Resistance (D. G. Miller, chairman) continued its study of methods for measuring the sulfate resistance of cements. A cooperative series of tests of ten cements is now in progress. The numerous test results reported by the subcommittee during the past two years contained much data of interest to cement investigators, and are closely related to the extensive work on "Tests of 106 Commercial Cements for Sulfate Resistance" reported by D. G. Miller and P. W. Manson in 1940.[3] Therefore, the reports submitted by the subcommittee in 1943 and 1944, including a suggested procedure for making the lean mortar test bar, are presented in Appendix III[4], in order to make the data readily available for study and comment.

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[1] In submitting this recommendation to Committee E-10 on Standards, Committee C-1 reported results of the letter ballot vote as follows: Of a voting membership of 78, 66 members returned their ballots, of whom 58 voted affirmatively, 4 negatively, and 4 members marked their ballots "not voting."

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 311 (1944).

The Working Committee on Fineness (R. L. Blaine, chairman) sponsored a series of cooperative tests to determine the day-to-day variations in fineness values determined by the turbidimeter[5] and the air permeability[6] methods. Fineness values were reported on approximately 1400 individual samples of cement, representing the product of 70 different mills in different parts of the country. The ratio of air permeability to turbidimeter fineness values of cements manufactured in different mills varied over a wide range. The day-to-day variation of this ratio for a cement manufactured at any one plant was attributed to many different factors. A report on these tests has been submitted to the members of Committee C-1. Because of the interest already manifest in the Blaine air-permeability fineness apparatus, and in order to promote uniformity in test procedure, the working committee has recently submitted for consideration by Committee C-1 a Proposed Method covering the apparatus and procedure which appears in Appendix IV.

The Working Committee on Strength (G. L. Lindsay, chairman) has for some time been engaged in preliminary tests of methods for comparing the performance of flow tables. Also, details are being arranged for early investigation of: (*1*) Mixing of mortars, with studies to be directed toward the development of a mechanical type mixer; and (*2*) reproducibility of flow and compressive strength test results, this study being regarded as necessary prior to considering revisions of flow table requirements.

The Working Committee on Additions (H. J. Gilkey, chairman) now has on hand an application to consider a material proposed as an addition, for grinding aid purposes, under the current A.S.T.M. standards for portland cements. Cooperating with the Technical Assistant of Committee C-1, there was prepared, for the subcommittee's information a digest of the many questions, tests, and requirements which had entered into the subcommittee's deliberations since its organization in 1936. With the benefit of study of that list of items, the subcommittee will present to Committee C-1 a memorandum proposed for ready answer of inquiries relating to the general requirements governing the tests or reviews of additions by Committee C-1.

The Working Committee on the Effects of Alkalies in Portland Cement (R. F. Blanks, chairman) has continued active study of its problems. The method employed in most laboratories for studying the reaction between aggregate and cement has been the mortar bar expansion test. Because of the differences sometimes found in the results of this test when made by a number of laboratories, the committee agreed that it should undertake a cooperative study to determine the dependability of such a test and the degree of reproducibility of results. Such a cooperative study was begun early last year, most of the members participating, as well as the Portland Cement Association, the National Bureau of

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 988 (1940).

[4] See p. 165.

[5] Standard Method of Test for Fineness of Portland Cement by the Turbidimeter, (A.S.T.M. Designation: C 115 - 42), 1944 Book of A.S.T.M. Standards, Part II, p. 47.

[6] "A Simplified Air Permeability Fineness Apparatus," by Raymond L. Blaine, ASTM BULLETIN, No. 123, August 1943, p. 51.

Standards, and the New Jersey State Highway Department. Five aggregates and six cements were distributed to ten laboratories. Two of the aggregates had been proven nonreactive. The total alkali content of the cements varied from 0.18 to 1.41 per cent. The laboratories were instructed to prepare three 1 by 1 by 10-in. mortar bars, 1:2.25 mix, water-cement ratio 0.50, for each of 30 combinations, using each cement with each aggregate. After 24 hours in the molds in a moist closet, the bars were to be removed from the molds, measured, and placed in sealed containers in which there was free water not in contact with the bars. The containers were to be stored at 70 F. and the bars measured at stipulated intervals. Some of the test data have already been collected and compared. The results of the cooperative study show poor agreement for the actual quantitative expansions secured for the various combinations of materials by the different laboratories. They do, however, indicate that reactive expansion is roughly proportional to the amount of alkalies present in the cement and that no expansions were secured with cement containing as little as 0.42 per cent alkali (expressed as $Na_2O + 0.658 K_2O$).

The Cement Reference Laboratory at the National Bureau of Standards has continued its work under the supervision of the Subcommittee on Cement Reference Laboratory (G. E. Warren, chairman). The field work has been on a smaller scale than usual. Forty-seven laboratories were inspected. The eighth inspection tour will be about completed by the end of 1945. The Public Roads Administration still makes use of the laboratory inspection service and has continued to give financial support. The laboratory cooperated in studies of details of apparatus and test procedure and is cooperating in endeavors to improve flow table requirements. Preliminary work has been done on a number of projects looking toward the preparation of publications on laboratory equipment.

In accordance with the wishes of Committee C-1, as expressed in the 1944 Annual Report, the laboratory revised the Manual on Cement Testing. Considerable time was devoted to editorial work incidental to the numerous revisions in the cement standards accepted last year, and a detailed index was prepared for the new edition of the compilation "A.S.T.M. Standards on Cement"[7] in an endeavor to make that rapidly growing publication more valuable and serviceable to its users.

Emergency Alternate Specifications for Portland Cement (**EA – C 150**).—The War Production Board rescinded Limitation Order L-179 on November 25, 1944. That order, designed to conserve materials and promote the national war effort, had placed certain limitations on the manufacture, storage, and testing of portland cement as covered in Emergency Specifications EA – C 150. The C-1 Technical Advisory Committee (J. L. Miner, chairman) had served to maintain contact between the War Production Board and Committee C-1. Under date of December 11, 1944, Committee E-10 on Standards took official action to withdraw Emergency Alternate Specifications EA – C 150 in line with the recommendation in the 1944 Annual Report of Committee C-1.

This report has been submitted to letter ballot of the committee which consists of 83 voting members; 61 members returned their ballot, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

P. H. Bates,
Chairman

G. E. Warren,
Secretary.

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[7] Issued as separate publication, December, 1944.

APPENDIX I

PROPOSED RECOMMENDATIONS AFFECTING STANDARDS ON CEMENT

The Sponsoring Committee on Portland Cement has submitted to Committee C-1 the following recommendations affecting cement standards. These recommendations have not yet been considered at a regular meeting of Committee C-1, and are presented here only as information and to promote discussion.

Standard Specifications for Portland Cement (C 150 – 44):[1]

Table 1.—In this table of chemical requirements delete the maximum limitation "50 per cent" on tricalcium silicate for type II cement.

Add the following footnote to the maximum limitation shown for sulfur trioxide for types I and III:

> The maximum limit for sulfur trioxide in types I and III cements shall be 2.5 and 3.0 per cent, respectively, when the calculated tricalcium aluminate content of the cement is in excess of 8 per cent.

Section 9.—Change Paragraph (*b*) to read as follows by the addition of the italicized words:

> (*b*) Cement remaining in bulk storage at the mill, prior to shipment, for a period greater than 6 months, *or cement in bags in local storage for a period greater than 3 months*, after completion of the tests, may be retested *before use*, and may be rejected if it fails to conform to any of the requirements of these specifications.

Tentative Specifications for Air-Entraining Portland Cement for Concrete Pavements (C 175 – 44 T):[1]

Title.—Change to read as follows by the omission of the words in brackets: "Tentative Specifications for Air-Entraining Portland Cement [for Concrete Pavements]."

Section 1.—Change the first sentence to read as follows by the omission of the words in brackets: "These specifications cover two types of air-entraining portland cement [for use in concrete pavements exposed to severe frost action]."

Section 3.—Change the final sentence in footnote 4 (*a*) from its present form: namely,

> The Vinsol resin may be added at the mill in the form of an aqueous solution of sodium resinate (the ratio of solid sodium hydroxide to Vinsol resin is 15 parts to 100 parts, by weight).

to read as follows:

> The Vinsol resin shall be added at the mill in the form of an aqueous solution of sodium resinate (15 parts sodium hydroxide, 100 parts Vinsol resin and not more than 1200 parts of water by weight).

Table 1.—In this table of chemical requirements delete the maximum limitation "50 per cent" on tricalcium silicate for type IIA cement.

Add the following footnote to the maximum limitation shown for sulfur trioxide for type IA:

> The maximum limit for sulfur trioxide in type IA cement shall be 2.5 per cent when the calculated tricalcium aluminate content of the cement is in excess of 8 per cent.

Standard Methods of Sampling Hydraulic Cement (C 183 – 44):[1]

Sections 3 and 4.—Combine these sections into the following new Section 3, renumbering subsequent sections accordingly:

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[1] 1944 Book of A.S.T.M. Standards, Part II.

3. *Sampling.*—The cement may be sampled by any of the methods described in the following Paragraphs (*a*) to (*d*):

(*a*) *From the Conveyor Delivering to Bulk Storage.*—One sample of 4 lb. or more shall be taken from at least each 2000 bags passing over the conveyor, except that the sample shall not represent more than 6 hr. of cement production. This may be secured by taking the entire test sample at a single operation, known as the "grab method," or by combining several portions taken at regular intervals, known as the "composite method." When obtaining a composite sample, it shall be secured by combining approximately equal weights of the cement taken at regular intervals, each portion representing approximately 40 bags. Automatic samplers may be used in obtaining samples.

(*b*) *From Bulk Storage at Points of Discharge.*—Sufficient cement shall be drawn from the discharge openings to obtain samples representative of the cement as determined by the appearance at the discharge openings of indicators placed on the surface of the cement directly above these openings before the drawing of the cement is started. One 4-lb. sample shall be taken for at least each 2000 bags, by either the "grab" or "composite" method as described in Paragraph (*a*).

(*c*) *From Bulk Storage by Means of Proper Sampling Tubes.*—When the methods described in Paragraphs (*a*) and (*b*) cannot be applied and when the depth of the cement to be sampled does not exceed 10 ft., samples may be obtained by proper tubes inserted vertically to the full depth of the cement. Samples so taken shall be obtained from points well distributed over the area of storage.

(*d*) *From Other Places.*—In all other cases, samples shall be taken from each 50 bags or fraction thereof in the lot and combined to form test samples. In the case of samples from trucks where the cement is being trucked from one mill, it is permissible to combine the samples from several trucks to form a test sample representing not more than 2000 bags. When bulk shipments are sampled, representative samples shall be taken from well-distributed points.

APPENDIX II

PROPOSED SPECIFICATIONS FOR PORTLAND BLAST-FURNACE SLAG CEMENT[1,2]

These are proposed specifications and are issued as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. These specifications cover the type of hydraulic cement designated as portland blast-furnace slag cement.

Definitions

2. (*a*) *Portland Blast-Furnace Slag Cement.*—Portland blast-furnace slag cement shall be an intimately interground mixture of portland cement and granulated blast-furnace slag. The slag constituent shall not exceed 65 per cent of the portland blast-furnace slag cement.

NOTE.—The portland cement constituent shall conform to the requirements of type I cement as prescribed in the Standard Specifications for Portland Cement (A.S.T.M. Designation: C 150).[3]

(*b*) *Granulated Blast-Furnace Slag.*—Granulated blast-furnace slag is the nonmetallic product consisting essentially of silicates and aluminosilicates of calcium which is developed simultaneously with iron in a blast furnace and is produced by rapidly chilling or quenching the molten material in water, steam, or air.

Additions

3. (*a*) Water or untreated calcium sulfate, or both, may be added in amounts such that the limits shown in Section 4 for the ignition loss and sulfur trioxide are not exceeded.

(*b*) Materials other than water or calcium sulfate may be added provided that they have been shown to be acceptable, in the amounts indicated, by tests carried out or reviewed by Committee C-1.

NOTE.—Tests to determine whether a proposed addition is acceptable will be carried out or reviewed by Committee C-1 on Cement, for those making requests. In the year following that in which an addition has been declared acceptable by the Committee, the name of the addition shall appear as an addendum to Section 3 and any definite limitation on the quantity to be used shall appear in the table of chemical or physical requirements in a revision of the specifications.

Chemical Requirements

4. (*a*) Portland blast-furnace slag cement shall conform to the chemical requirements prescribed in Table I.

TABLE I.—CHEMICAL REQUIREMENTS.

Magnesium oxide (MgO), max., per cent..	5.0
Sulfur trioxide (SO_3), max., per cent......	2.5
Manganic oxide (Mn_2O_3), max., per cent..	1.5
Sulfide sulfur (S), max., per cent.........	2.0
Insoluble residue, max., per cent.........	1.0
Loss on ignition, max., per cent..........	3.0

(*b*) The granulated blast-furnace slag constituent shall conform to the following composition:

$$\frac{CaO + MgO + \frac{1}{3}Al_2O_3}{SiO_2 + \frac{2}{3}Al_2O_3} \geqq 1$$

NOTE.—Granulated blast-furnace slag having a chemical composition within the following

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[1] These proposed specifications are under the jurisdiction of the A.S.T.M. Committee C-1 on Cement.

[2] Published as information June, 1945.

[3] 1944 Book of A.S.T.M. Standards, Part II.

ranges generally meets the requirements of the above formula:

Calcium oxide (CaO), per cent	40 to 50
Silicon dioxide (SiO_2), per cent	30 to 40
Aluminum oxide (Al_2O_3), per cent	8 to 18
Ferrous oxide (FeO), per cent	0 to 1
Magnesium oxide (MgO), per cent	0 to 8
Manganic oxide (Mn_2O_3), per cent	0 to 2
Sulfide sulfur (S), per cent	0 to 2

Physical Requirements

5. Portland blast-furnace slag cement shall conform to the physical requirements prescribed in Table II.

TABLE II.—PHYSICAL REQUIREMENTS.

Fineness, amount retained when wet-sieved on No. 325 (44-micron) sieve, **max.**, per cent	15
Soundness:	
Autoclave expansion or contraction, max., per cent	0.20[a]
Time of setting:	
Vicat needle:	
Initial set, min., not less than	45
Final set, hr., not more than	10
Compressive strength, psi.:[b]	
The compressive strength of mortar cubes, composed of 1 part cement and 2.75 parts graded standard sand, by weight, prepared and tested in accordance with Method C 109, shall be equal to or higher than the values specified for the ages indicated below:	
1 day in moist air, 2 days in water	900
1 day in moist air, 6 days in water	1 800
1 day in moist air, 27 days in water	3 000
Tensile strength, psi.:[b]	
The tensile strength of mortar briquets, composed of 1 part cement and 3 parts standard sand, by weight, prepared and tested in accordance with Method C 190, shall be equal to or higher than the values specified for the ages indicated below:	
1 day in moist air, 2 days in water	150
1 day in moist air, 6 days in water	275
1 day in moist air, 27 days in water	350

[a] Three 1 by 1 by 10-in. bars shall remain firm and hard and show no signs of distortion, cracking, checking, pitting, or disintegration when subjected to the autoclave expansion test.

[b] The purchaser should specify the type of strength test required. In case he does not so specify, the requirements of the compressive strength test only shall govern.

Manufacturer's Statement

6. (*a*) At the request of the purchaser, the manufacturer shall state in writing the source, amount and composition of the granulated blast-furnace slag and the composition of the portland blast-furnace slag cement.

(*b*) The composition of the portland blast-furnace slag cement shall conform to that shown in the statement of the manufacturer within the following tolerances:

	Tolerance, per cent
Calcium oxide (CaO)	±3
Silica (SiO_2)	±3
Alumina (Al_2O_3)	±2

Packaging and Marking

7. When the cement is delivered in packages, the words "Portland blast-furnace slag cement," the name and brand of the manufacturer, and the weight of the cement contained therein shall be plainly marked on each package. Similar information shall be provided in the shipping advices accompanying the shipment of packaged or bulk cement. A bag shall contain 94 lb. net. A barrel shall consist of 376 lb. net. All packages shall be in good condition at the time of inspection.

Storage

8. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

Inspection

9. Every facility shall be provided the purchaser for careful sampling and inspection, either at the mill or at the site of the work, as may be specified by the purchaser. The following periods from time of sampling shall be allowed for completion of testing:

3-day test	8 days
7-day test	12 days
28-day test	33 days

Rejection

10. (*a*) The cement may be rejected if it fails to meet any of the requirements of these specifications.

(*b*) Cement remaining in bulk storage at the mill, prior to shipment, for a period greater than 6 months after completion of the tests may be retested and may be rejected if it fails to conform to any of the requirements of these specifications.

(*c*) Packages varying more than 5 per cent from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages at random, is less than that specified, the entire shipment may be rejected.

Methods of Testing

11. The cement shall be sampled and the properties enumerated in these specifications shall be determined in accordance with the following methods of the American Society for Testing Materials:

(*a*) *Sampling.*—Standard Methods of Sampling Hydraulic Cement (A.S.T.M. Designation: C 183).[3]

(*b*) *Chemical Analysis.*—Standard Methods of Chemical Analysis of Portland Cement (A.S.T.M. Designation: C 114 - 44)[3] and Tentative Methods of Chemical Analysis of Portland Cement (A.S.T.M. Designation: C 114 - 44 T).[3]

(*c*) *Fineness.*—Standard Method of Test for Fineness of Portland Cement by the Turbidimeter (A.S.T.M. Designation: C 115),[3] using the No. 325 (44-micron) sieve and the procedure described in Section 12 of this method.

(*d*) *Autoclave Expansion.*—Standard Method of Test for Autoclave Expansion of Portland Cement (A.S.T.M. Designation: C 151).[3]

(*e*) *Time of Setting.*—Standard Methods of Test for Time of Setting of Hydraulic Cement by the Vicat or Gilmore Needles (A.S.T.M. Designation: C 191),[3] using the Vicat needle.

(*f*) *Compressive Strength.*—Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars (A.S.T.M. Designation: C 109).[3]

(*g*) *Tensile Strength.*—Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (A.S.T.M. Designation: C 190).[3]

APPENDIX III[*]

REPORT ON COMPARATIVE SHORT-TIME TESTS FOR SULFATE RESISTANCE OF 121 COMMERCIAL CEMENTS[1]

PREPARED BY DALTON G. MILLER[2] AND CHARLES G. SNYDER[3] AS A REPORT OF THE WORKING COMMITTEE ON SULFATE RESISTANCE

This report consists for the most part of the report of the Working Committee on Sulfate Resistance, of Committee C-1 on Cement, prepared for presentation in 1943. It includes, however, under a separate heading the 1944 Report on Additional Mortar Bar Tests. The two reports should be considered together in order to get a fair picture of these studies having to do with short-time tests for sulfate resistance.

The agencies that made tests to which direct reference is made were:

California Portland Cement Co.,
Board of Water Supply, City of New York,
National Bureau of Standards,
National Research Council of Canada,
Portland Cement Association,
Public Roads Administration, and
Cooperative Laboratory, University Farm, University of Minnesota.

Five-year sulfate resistance tests of 2 by 4-in. concrete cylinders, 1:3 mix, of the 121 cements from which stored samples were used in these short-time tests were completed in 1941 under conditions of exposure as follows: Some cylinders of each cement were continuously stored in the laboratory in 1 per cent solutions of sodium sulfate, some in 1 per cent solutions of magnesium sulfate, and some in the water of Medicine Lake, South Dakota. During the 5 yr., the water of this lake averaged 12 per cent total salts, of which two-thirds were magnesium sulfate and one-fourth was sodium sulfate. Resistance of the cylinders stored in the laboratory was determined by length changes while resistance of the Medicine Lake cylinders was determined by strength ratios calculated from compression tests at 1 and 5 yr. of the Medicine Lake cylinders and cylinders stored in tap water in the laboratory. Results of the 5-yr. tests of 106 of these cements have been published[4] and indicated close correlation between sulfate resistance of the cements and the percentage of the calculated compound tri-calcium aluminate, commonly referred to as C_3A.

The primary purpose for making the tests here reported upon has been to find, if possible, a reliable short-time acceptance test for cements to be used in the manufacture of drain tile, irrigation pipe, dams, and structures of many other types used in soil conservation projects, and concrete construction of all kinds that in service must resist the action of soils and waters rich in sulfates.

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[*] This report constitutes Appendix III of the 1945 Report of Committee C-1 on Cement.

[1] Paper No. 2229, Scientific Journal Series, Minnesota Agricultural Experiment Station.

[2] Dalton G. Miller, Senior Drainage Engineer, Division of Drainage and Water Control, Soil Conservation Service, U. S. Department of Agriculture, in charge of laboratory at University Farm, St. Paul, Minn., conducted under a cooperative agreement of the Soil Conservation Service of the U. S. Department of Agriculture, The Agricultural Experiment Station of the University of Minnesota, and the Division of Water Resources and Engineering of the Department of Conservation, State of Minnesota.

[3] Instructor and Assistant in Agricultural Engineering, Department of Agriculture, University of Minnesota.

[4] Dalton G. Miller and Philip W. Manson, "Tests of 106 Commercial Cements for Sulfate Resistance." (Minnesota Agricultural Experiment Station *Paper No. 1821*, Scientific Journal Series); also *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 988 (1940).

LEAN MORTAR BAR TESTS

The tests of lean mortar bars were made by the following cooperators:

California Portland Cement Co. (Hanna),
National Bureau of Standards (Gause),
Portland Cement Association (Gonnerman), and
Cooperative Drain Tile Laboratory, University Farm, St. Paul, Minn. (Miller).

All lean mortar bar tests were made during 1941 and 1942, except those by the National Bureau of Standards which were made during 1936.

The California Portland Cement Co. bars were 1 by 1-in. in cross-section, with effective gage lengths of 5 in. The mix was 1:6 by weight of Ottawa standard sand, the mixing water being 53 per cent by weight (80 per cent by volume) of the dry cement. After 42 to 44 hr. in the molds, the bars were removed and stored in tanks with running water and, when 14 days old, individual bars were exposed to the solutions in 2-qt. covered jars. All solutions were replaced by fresh ones every 7 days. Four exposure solutions were used, namely, tap water, sodium sulfate 0.15 M, magnesium sulfate 0.15 M, and a combination solution of sodium sulfate 0.25 M and magnesium sulfate 0.25 M. Tests were made on a single run of bars, one from each batch of the four solutions.

The Portland Cement Association bars were 1 by 1-in. in cross-section with effective gage lengths of 10 in. The mix, water-cement ratio, and solutions were the same as for the California Portland Cement Co. bars. All bars were held in the molds 48 hr., then stored in water and exposed to the solutions when 14 days old. Solutions were changed every 7 days. Each test result, as reported, is the average of two bars from each batch, one bar of which was lightly brushed each week with a steel wire brush. Both length changes and sonic changes were reported by the Association. With but few exceptions, brushing the bars seemed to have little influence; consequently the results of the Association's tests here reported are averages for two bars, one of which was brushed.

The National Bureau of Standards bars were 1 by 1 by 6 in., evidently of effective gage length of 5 in., of cement and Ottawa standard sand in the proportions of 1:5 by weight, mixed with 9.3 per cent of water by weight of the dry materials (about 56 per cent by weight of the dry cement). The bars were made in duplicate, one set being stored in the solutions after two days in water while the other set was stored in water six days before placing in 10 per cent (0.78 M) solutions of sodium sulfate in individual containers. Solutions were not renewed during the period of the test. For further details of the Bureau of Standards tests reference should be made to the 1941 article.[5]

Some 4200 bars were made at University Farm. The bars were 1 by 1 in. in cross-section with effective gage lengths of 5 in. The mix was 1:5 of cement and Ottawa standard sand, except for about 500 bars made with a 1:6 mix. Results were so erratic for the 1:6 bars that it was early decided so lean a bar held little promise for use in an Acceptance test. Results of tests of these 1:6 bars are not here reported. Normal consistency was determined for each cement, and the quantity of mixing water used with each cement was calculated in accordance with Table I[6] of A.S.T.M. Standard Methods of Sampling and Physical Testing of Portland Cement C 77 – 40.[7] Bars were held in the moist closet 48 hr., then stored in water for 5 days and placed in solutions when 7 days old. Test results are reported for bars stored in the following seven solutions at University Farm:

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[5] G. Rupert Gause, "Studies of the Sulfate Resistance of Portland Cements," ASTM BULLETIN, No. 112, October, 1941, p. 17.

1. Sodium Sulfate:
    - 0.15 *M* (2.1 per cent)
    - 0.50 *M* (6.7 per cent)
    - 0.78 *M* (10 per cent)
2. Magnesium Sulfate:
    - 0.15 *M* (1.8 per cent)
    - 0.50 *M* (5.7 per cent)
    - 0.78 *M* (8.6 per cent)
3. Combination Solution, 0.50 *M* consisting of:
    - 0.25 *M* (3.4 per cent) sodium sulfate
    - 0.25 *M* (2.9 per cent) magnesium sulfate

The ratio of volume of solution to volume of the bars in all containers was approximately 4 to 1, and all solutions were changed at intervals of 7 days with the exception of the two 0.78 *M* solutions which were not changed during the test. Six bars were made to a batch and the general practice was to put individual bars from each batch in solutions of different strengths. Length changes as reported are in practically all cases averages for three or more bars made on different days.

Evaluation of Lean Mortar Bar Tests by Length Changes:

At all laboratories, metal inserts were cast in the ends of the bars and length changes were determined by over-all measurements between exterior ends of the inserts. The results were reported as percentage length changes based on the effective gage length of the bars, assuming the gage reading immediately before placing the bars in the solutions as the basis of computation. Readings were made of all bars at 7-day intervals.

After study of all data, the results were condensed in Table III by selecting the length changes at the shortest period of exposure to the various solutions as seemed best to correlate with the long-time tests of the cylinders as recorded in Table I. Then, in Table V, effort is made to translate the data of Table III into understandable values by indicating the number of cements of each of the 12 groups that did not exceed certain upper limits as recorded at the top of each of the columns. It will be noted that these limits differ for solutions of different strengths and for the two types of bars, namely, 1:5 and 1:6 mixes.

In each case, effort was made to fix a limit that passed a high proportion of the cements in the upper six groups and failed most of the cements in the lower six groups. It will be noted that some of the limits indicated are far from satisfactory, although in all cases an attempt was made to select the most satisfactory one. This suggests that certain of these lean mortar bar tests do not hold much in the way of possibilities for a performance test.

The National Bureau of Standards lean mortar bar tests of these 121 cements were of samples submitted in 1935 to 1937 for the chemical analyses as reported in Table II. Most of the Bureau's tests were made during 1936 when the cements were fresh, whereas, the bars at all the other laboratories were made during 1941 and 1942 after the cements had been in storage in air-tight containers 5 or 6 yr. Mention is made of this in order to draw attention to the parallel tests of the bars in the 0.78 *M* sodium sulfate solutions as recorded in columns A and B of Tables III and V. In spite of the fact that the National Bureau of Standards bars of these cements were made some 6 years earlier than were the bars at University Farm, the general agreement of test results was satisfactory, particularly for the more resistant of the cements. Many of the differences that did occur may have been due, at least in part, because the Bureau of Standards tests were of single bars while the tests at University Farm were in nearly all cases averages for three or four bars made in batches several weeks apart.

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[6] This information also appears in Table II of the Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 – 44), 1944 Book of A.S.T.M. Standards, Part II, p. 70.

[7] 1942 Book of A.S.T.M. Standards, Part II, p. 33.

Inspection of the data of Tables III and V discloses that the test results of the lean mortar bars in the 0.15 *M* solutions of sodium sulfate were in fairly close agreement at the three laboratories that used this solution, with slightly better distribution of results among the 12 groups of cements for the 1:5 bars at University Farm than for the 1:6 bars at either the California Portland Cement Co. laboratory or that of the Portland Cement Association. Identically the same statement may be made regarding the bars in the 0.15 *M* solutions of magnesium sulfate except that agreement of results of the three laboratories was less exact with considerably better distribution among the 12 groups of cements for the 1:5 bars than for the 1:6 bars. Agreement of results was less exact for tests of the bars in the 0.50 *M* mixed solutions at the three laboratories than for either of the 0.15 *M* solutions of the separate salts, while distribution of the cements meeting the limits indicated among the 12 groups was somewhat better for the 1:5 bars at University Farm than for the 1:6 bars at the other two laboratories but was, in general, less satisfactory than for the two 0.15 *M* solutions.

Only at University Farm were bars stored in sodium sulfate solutions of 0.50 *M* and in magnesium sulfate solutions of 0.50 *M* and 0.78 *M*. The 1:5 bars in the 0.50 *M* solutions of sodium sulfate gave results that came fairly near to parallelling the long-time performance tests of the 121 cements. Fixing a limit of 0.10 per cent length change for the bars so exposed passes 32 cements distributed among the 12 groups as shown in Table V.

Results with the bars stored in the 0.50 *M* solutions of magnesium sulfate were erratic and passed a total of 51 of the 121 cements for the limit of expansion of 0.15 per cent. Distribution of these 51 cements throughout the 12 groups was far from satisfactory as inspection of the results in Table V will show.

Results with the bars stored in the 0.78 *M* solutions of magnesium sulfate were even more unsatisfactory than were those with the bars in the 0.50 *M* solutions. As stated previously, the 0.78 *M* solutions of magnesium sulfate were not changed during the tests. This particular solution was used chiefly in order to have a direct comparison of behavior of bars so exposed with those in the 0.78 *M* solutions of sodium sulfate.

From the foregoing tests, it may be said that results with the two solutions 0.15 *M* sodium sulfate and 0.15 *M* magnesium sulfate were the most dependable of any of the solutions used. Bars leaner than 1:5 were found to give so many erratic results that it was evident that the test frequently became rather one of uniformity of workmanship in making the bars than of the conditions to which the bars were exposed. This was particularly true of 1:6 bars exposed to solutions of magnesium sulfate. It was also found that even 1:5 bars gave decidedly erratic results when exposed to any of the magnesium sulfate solutions with molarity greater than 0.15 *M*. Even in magnesium sulfate solutions of 0.15 *M* it sometimes happened that individual 1:5 bars went completely out of line, indicating that the margin between good and poor workmanship in making the bars was just about as narrow as practicable for an acceptance test. The lean mortar bar test comes nearest to approximating exposure of concrete to the action of sulfate waters of any of the tests tried, and the results are reasonably well in agreement with the 5-yr. performance records of the 121 cements. The weakness of this test is the difficulty encountered in consistently making lean mortar bars of satisfactory uniformity. It is believed that if this fact be kept in mind when the bars are made and the routine, as suggested in the Appendix, or any other routine that may be agreed upon, be meticulously followed, the results obtained at different laboratories will be in agreement satisfactory for an acceptance test. In reply to possible criticism that sodium sulfate solution and magnesium sulfate solution of 0.15 *M* are weaker than are to be desired for an acceptance test, it will be said that concrete in service is rarely exposed to sulfate solutions stronger than this. Also, using solutions of this strength in a laboratory test does seem to rate the sulfate-resisting properties of a cement quite accurately. It is true that the over-all time for this test will require 5½ or 6 weeks, allowing for the making of at least three batches of bars on different days. However, nothing in the work covered by this report indicates that this time can be satisfactorily shortened, either by using bars leaner than 1:5 or by using stronger solutions.

Evaluation of Lean Mortar Bar Tests by Sonic Determinations:

Possibilities of a sonic (dynamic) method for testing concrete have received considerable attention during recent years by a number of workers. An extremely valuable summarization of work along this line is presented by Obert and Duvall in their paper "Discussion of Dynamic Methods of Testing Concrete with Suggestions for Standardization."[8] That paper contains a bibliography on the sonic test. The only laboratory to make sonic tests of the 121 cements was the Portland Cement Association using an electrical apparatus and bars of dimensions 1 by 1 by 11¼ in. The sonic values recorded as percentages in Table IV were obtained by Mr. Gonnerman, "by squaring the frequency of vibration (number per second required to produce resonance for the fundamental mode) obtained from the specimen after exposure to sulfate water, or solution, subtracting this from the square of the frequency of vibration obtained before exposure of the specimen, and dividing this value by the square of the frequency of vibration before exposure. This value is then multiplied by 100 to put it on a percentage basis." The minus sign was arbitrarily used to indicate lowering of the frequency of vibration which resulted as specimens deteriorated due to storage in sulfate solutions.

Originally it had been planned also to use this method at University Farm, but the 1 by 1 by 6¼-in. bar was of dimensions unsuitable for the sonic test with the apparatus at hand. It therefore became a matter of making bars of other dimensions or of getting electrical equipment that would measure the frequency of vibration of the shorter bar. Either of these two alternatives meant too much added work and expense to be considered for the duration of the War.

The sonic determinations of 1 by 1 by 11¼-in. bars of 1:6 mix gave values as recorded in Table III, columns O, P, and Q. Results were closest in agreement with the 5-yr. tests of these cements for the bars exposed to the 0.15 *M* solutions of sodium sulfate. Agreement was poorest for the bars in the 0.50 *M* combination solution and not much better for the bars in the 0.15 *M* solutions of magnesium sulfate. It now seems unfortunate that 1:5 bars were not used instead of 1:6 bars in view of the generally erratic results obtained by the various laboratories with the 1:6 bars. The results as reported for the sonic test indicate that this method of determining the physical condition of the bars was, in general, satisfactory. Whether the sonic test has any practical advantages over the long proven and more direct method of change of length measurements for an acceptance test for sulfate resistance of a cement is still very much open to question.

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[8] *Proceedings*, Am. Soc. Testing Mats., Vol 41, p. 1053 (1941).

Summary of Lean Mortar Bar Tests:

Briefly, the results of the lean mortar bar tests appear to warrant the following conclusions:

1. Results of tests of bars in solutions of sodium sulfate were less erratic than were those of identical bars in solutions of magnesium sulfate.
2. Test results of bars in the 0.15 *M* solutions were, in general, less erratic than were test results of identical bars in the 0.50 *M* solutions.
3. Results with 1:5 Ottawa standard sand bars were less erratic than results with 1:6 Ottawa standard sand bars. This difference was particularly marked for the bars stored in the 0.50 *M* combination solutions of sodium and magnesium sulfate.
4. For a routine laboratory performance test, it appears that 1:5 bars in the following two solutions, changed every 7 days, hold most in the way of possibilities for an acceptance test of any of the bar tests made in these studies:

0.15 *M* (2.1 per cent) sodium sulfate, and
0.15 *M* (1.8 per cent) magnesium sulfate.

MERRIMAN SLAB TEST

Merriman slab tests were made by the following cooperators:

Board of Water Supply, City of New York (Stadtfeld), and
National Research Council of Canada (Wolochow).

Results of this test as reported by Mr. Stadtfeld and Mr. Wolochow are recorded in Table IV. The data show that agreement of the two laboratories was satisfactory to the extent that the most resistant of the cements passed the test and generally the least resistant failed to pass in both laboratories. Agreement of results for the in-between cements was least satisfactory. It appears that more rigid requirements as to evaluating the results of the Merriman slab test are desirable and the thought naturally arises that rating the slabs after exposure for some period in excess of 28 days might accomplish this purpose. A description of the Merriman slab test appears in the Appendix. However, inspection of the data of Table IV does not give much encouragement along this line because even after 90 days exposure the Board of Water Supply would have passed 74 and the National Research Council 66 of the 121 cements. A period of exposure longer than 90 days would seriously reduce the value of any test from an acceptance standpoint. In all fairness to the Merriman slab test, it must be said that the results recorded in Table IV are reasonably in accord with the long-time performance records of the 121 cements to sulfate waters, the chief criticism being that, as applied, it is not severe enough to be entirely satisfactory as an acceptance test. It has been suggested that the slab test could perhaps be accelerated by transferring the slabs to fresh solutions every few days.

MERRIMAN SUGAR SOLUBILITY TEST

Merriman sugar solubility tests were made by the following cooperators:

Board of Water Supply, City of New York, and
National Research Council of Canada.

With possibly nine exceptions, results of the sugar test by the two laboratories, as recorded in Table IV, are in satisfactory agreement, and correlation is fair with the performance records of the 121 cements as determined by the 5-yr. tests. A description of the Merriman sugar solubility test appears in the Appendix. An indicated weakness of this test from an acceptance standpoint is in the distribution of the cements with low sugar solubility indices among the 12 groups. If 10 ml. of 0.5 *N* HCl be fixed as the upper limit of sugar solubility for acceptance, using averages of the Board of Water Supply and National Research Council results, 42 cements that passed would be distributed among the 12 groups as follows: 8, 7, 7, 4, 1, 5, 4, 2, 1, 3, 0, 0. Fixing limits other than 10 ml. of 0.5 *N* HCl does not improve this distribution. Therefore, used alone, the sugar solubility of a cement does not appear to be entirely satisfactory as an index of sulfate resistance. However, if the sugar solubility of these cements, as determined, be considered in conjunction with the quantity of tri-calcium aluminate compound, as calculated, this test gives indications of definite possibilities. As a single example, if 25 per cent be fixed as the upper limit of sugar solubility, using the averages of the BWS and NRC results as recorded in Table IV, at the same time limiting C_3A to 7.0 per cent, 30 of the 121 cements would meet these requirements distributed among the 12 groups as follows:

Group	Number of Cements Passing
I	10
II	8
III	7
IV	2
V	1
VI	2
VII to XII	0

PAUL'S WATER FLOC TEST

Paul's water floc test was made by the following:

Public Roads Administration (Kelley),
Research Council of Canada, and
Cooperative Drain Tile Laboratory, University Farm, St. Paul, Minn.

Agreement of results of this test at the three laboratories were, for the most part, fairly well in line. Differences were most pronounced for the cements very low and very high in floc. Results by Public Roads Administration were mostly lower than those reported by the other two laboratories. This may have been due to interpretation of the last clause of the sentence "If a gelatinous precipitate is present, transfer onto filter paper, and wash the test tube three times by decantation with about 40 ml. of distilled water for each decantation, *gently agitating the tube each time without disturbing the set cement.*" (See the Appendix for the routine of Paul's Water Floc Test.) Differences of appreciable magnitude occur depending upon how "gently" the tube is agitated. In the laboratory at University Farm it was found by experimentation that more consistent results followed when the practice was to "shake as hard as necessary to remove the floc without disturbing the set cement." This practice gave reasonably consistent results and, of course, somewhat higher in many cases than did "gently agitating." Also, while not known for sure, results by PRA for many of the cements low in floc seem to have been reported as 0.00 per cent when the liquid looked clear without actually filtering and weighing any possible residue. For practical use to which this test might be put as an acceptance test for sulfate resistance this is of small importance and is mentioned merely to account for certain differences in recorded results that seem to be due to slight variations in the routine of the test.

If a limit of 0.80 per cent floc be fixed for sulfate resistance, the cements passing would be distributed among the 12 groups as follows based on the tests of the three laboratories:

Group	Laboratory			Passing in All Three Laboratories
	PRA	NRC	UF	
I	10	10	10	10
II	9	8	9	8
III	9	7	7	7
IV	4	4	4	4
V	3	1	1	1
VI	5	3	2	2
VII	2	1	2	1
VIII	1	1	1	1
IX	0	0	0	0
X	1	0	0	0
XI	1	0	0	0
XII	0	0	0	0
Totals	45	35	36	34

Correlation of results of the floc test with the performance records of these 121 cements, while not ideal for an acceptance test for sulfate resistance, certainly does not miss the mark very far.

AUTOCLAVE EXPANSION TEST

All 121 cements were autoclaved by Public Roads Administration with results as shown in Table IV. In general, those cements low in expansion were those of greatest resistance to sulfates, while those showing greatest expansion in the autoclave were low in resistance. The correlation is fair but hardly usable alone as a performance test for sulfate resistance.

GENERAL CONCLUSIONS

All of the short-time tests, even including expansion in the autoclave, gave results of a pattern strikingly similar to the 5-yr. sulfate resistance of the 121 cements. Elsewhere in the report, at the end of the discussion of each of the tests, effort has been made to summarize the results and will not be repeated here except again to point out that, all things considered, results with lean mortar bars were most nearly satisfactory for 1:5 bars stored in solutions of 0.15 M Na_2SO_4 and 0.15 M $MgSO_4$. Fixing limits of 0.02 per cent expansion for the 1:5 bars made at University Farm and stored in each of these solutions would have passed 35 of the 121 cements, distributed throughout the 12 groups as follows:

Group	Number of Cements Passing in Both Solutions
I	10
II	9
III	8
IV	3
V	3
VI	1
VII	0
VIII	1
IX to XII	0
Total	35

1944 REPORT ON ADDITIONAL MORTAR BAR TESTS

The agencies that cooperated in the work on which this 1944 report is based were:

California Portland Cement Co.,
California Highway Department,
Portland Cement Association, and
Coöperative Laboratory, University Farm.

Particular mention is made of the 1943 report, given earlier, because this 1944 report is much in the nature of an addition to that of a year ago.

Tables VI and VII show results of tests of 1:5 bars 1 by 1 in. in cross-section made of Ottawa standard sand

and 10 brands of cement and stored in water and in 0.15 *M* solutions of Na_2SO_4 and $MgSO_4$. Chemical analyses of the 10 lots of cement used in the tests given in Table VII are recorded in Table VIII. The chemical analyses were made by the Portland Cement Association and include the determination of a number of minor constituents not ordinarily reported. Lots of these same 10 brands of cement were among the 121 collected in 1935 and 1936, and variously tested as reported upon a year ago. Analyses by the National Bureau of Standards of the original lots of the 10 cements will be found in Table II of the 1943 report. The identifying numbers and the calculated C_3A content of the two lots of cements follow:

Collected, 1935		Collected, 1943	
Cement Number	C_3A Content, per cent	Cement Number	C_3A Content, per cent
405	5.1	779	6.5
426	4.1	780	6.3
390	5.3	781	6.6
441	7.1	782	8.1
614	8.9	783	10.3
384	9.7	784	9.5
486	9.0	785	9.4
411	11.9	786	11.0
417	11.0	787	12.1
483	11.7	788	11.2

Study of the data of Table VI shows that in general there was fair agreement in the length changes of bars of the three lots of cement in the sulfate solutions even though there was a spread of 8 yr. in the manufacture of the cements and considerable modification of the composition of some of them. Correlation was best for the more resistant cements. In general, the results of Table VI indicate that possibilities are good for reproducing test results of lean mortar bars made at a single laboratory.

In Table VII are shown tests of lean mortar bars made at 4 laboratories. Bars 5 in. long were made at each of the laboratories and 10-in. bars were made at two of them. Correlation of results obtained by the four laboratories was disappointingly poor. It seems possible that differences in fabrication of the bars is the most likely cause for differences in the test results as reported.

Considering only the tests of the 5-in. bars from the 4 laboratories, it is evident that those of the University Farm, Portland Cement Association, and California Highway Department laboratories correlated with each other somewhat better than they did with tests of the California Portland Cement Company laboratory. This is definitely true for the bars in the Na_2SO_4 solutions and is questionably true for the bars in the $MgSO_4$ solutions. As a matter of fact, in all the bar tests made in connection with these studies reported upon in 1943 and 1944, correlation of results invariably has been poorest in the $MgSO_4$ solutions irrespective of solution strengths and whether 1:5 or 1:6 bars.

In the 1943 report it was stated that "Fixing limits of 0.02 per cent expansion for the 1:5 bars made at University Farm and stored in each of these solutions (referring to 0.15 *M* Na_2SO_4 and 0.15 *M* $MgSO_4$) would have passed 35 of the 121 cements," which are distributed throughout the 12 groups, as shown in the tabulation given in the 1943 report.

If these same limits be applied to the later tests of the 5-in. bars made at the UF and CHD laboratories, it is found that the 3 cements that passed and the 7 that failed to pass were identical for these two laboratories. The cements that passed were Nos. 779, 780, and 781 with percentages of the C_3A calculated compound of 6.5, 6.3, and 6.6, respectively, while for the seven cements that failed C_3A ranged from 8.1 to 12.1 per cent.

Conclusions:

In conclusion, it is the opinion of the Working Committee on Sulfate Resistance that additional work still is needed on the lean mortar bar test before definite conclusions can be reached as to its usefulness. The Working Committee feels this is a matter of importance because fallible as the lean mortar bar test can be, it is believed to hold most in the way of possibilities of any short-time test for sulfate resistance so far devised. If the difference in behavior of bars from two laboratories is chiefly due to variations of tamping by different operators it should not be too difficult to standardize satisfactorily the details of this operation, but in order to do this, additional work will be necessary. Therefore, the Working Committee recommends that another series of bar tests be run in the near future providing at least 6 laboratories will cooperate.

NOTE.—Another series of tests was subsequently begun and is in active progress.

See Appendix, p. 192.

TABLE I.—RESULTS OF TESTS MADE IN CONNECTION WITH THE DETERMINATION OF SULFATE RESISTANCE OF THE 121 CEMENTS OF TABLE II.

The 121 cements in the 12 groups are arranged in descending order of resistance based on averages for the three exposure conditions.[a] The expansion results indicate the time required to increase in length 0.01 in.[b]
Test results of cylinders are in all cases averages for 5 cylinders made on different days.

Series Number	Cement Number	Strength Tests									Expansion Tests as of May 1, 1945	
		Tension Tests of Standard Briquets, psi.			Compression Tests of 2 by 4-in. Cylinders, psi.						Months Required for Cylinders Stored in 1 per cent Solutions to Increase in Length 0.01 in.[b]	
		Moist Closet			Tank Specimens				Medicine Lake Specimens[c]			
		3 days	7 days	28 days	7 days	28 days	1 yr.	5 yr.	1 yr.	5 yr.	$MgSO_4$	Na_2SO_4
GROUP 1												
1584	611	260	335	390	4310	6160	9600	8710	8010 (83)	7410 (85)	120+	120+
1599	631	310	370	445	4680	5120	9040	8750	8050 (89)	8030 (92)	119+	119+
1551	531	185	255	355	2810	5230	8130	8940	7080 (87)	7820 (88)	121+	121+
1511	405	275	340	415	4030	5820	7120	8490	7060 (99)	6720 (79)	122+	122+
1568	591	240	295	345	3910	4180	7010	7660	6440 (92)	6110 (80)	120+	120+
1571	576	200	....	315	3220	5080	6830	8370	7690 (113)	6230 (74)	120+	120+
1518	426	240	295	380	3890	5370	8750	9620	7820 (89)	6620 (69)	122*	122+
1620	647	255	325	410	4610	6470	7150	9430	7750 (108)	6770 (72)	110+	110+
1596	628	300	360	410	4410	5730	8130	9440	8120 (100)	7860 (83)	119+	119+
1576	582	225	295	290	3770	4830	7650	7980	6720 (88)	6600 (83)	120+	120+
Average		250	320	375	3960	5400	7940	8740	7470 (95)	7020 (81)		
GROUP 2												
1580	596	300	375	445	5130	5760	8110	8730	8510 (105)	5960 (68)	113	120+
1505	387	315	410	445	5230	5980	7380	8650	6470 (88)	7020 (81)	122*	122+
1593	621	130	....	460	2710	4880	8450	7640	8060 (95)	4810 (63)	119+	119+
1506	390	280	325	380	4400	5200	7480	7690	6100 (82)	6620 (86)	122+	122+
1543	507	275	345	465	4130	5940	8670	9180	7610 (88)	7040 (77)	121+	121+
1583	605	275	305	410	4300	5420	8640	9150	8040 (93)	6920 (76)	120*	120+
1563	561	320	430	470	5010	6520	7850	8380	7340 (94)	5070 (61)	121*	119*
1507	393	355	390	445	5720	6400	7670	7850	5910 (77)	4900 (63)	122*	122*
1537	489	255	300	370	3880	5630	7780	9000	7290 (94)	5930 (66)	121*	121+
1554	543	250	370	400	4800	6040	8600	9310	8060 (94)	6240 (67)	121*	121+
Average		275	360	430	4530	5780	8060	8560	7340 (91)	6050 (71)		
GROUP 3												
1547	516	295	355	445	4920	6680	7480	9050	7570 (101)	6360 (70)	121*	121*
1503	381	220	315	385	3690	5970	6840	7000	6550 (96)	6040 (86)	123*	111
1579	608	235	305	410	4780	6160	8960	8770	7350 (82)	5460 (62)	112	120+
1546	513	265	375	385	4150	5080	7800	8190	7190 (92)	5690 (70)	121+	121*
1523	441	275	360	430	4000	5520	7700	9390	5990 (78)	2810 (30)	122*	122+
1637	681	255	285	405	4950	6300	7210	8220	6010 (83)	4420 (54)	81	119+
1628	665	305	380	435	5190	6990	7200	9560	6050 (84)	4080 (43)	110*	110*
1619	646	290	345	440	4960	6330	7170	9280	5850 (82)	5380 (58)	110*	100
1639	683	275	295	325	4430	5350	6970	8370	5210 (75)	4090 (49)	90	109+
1616	643	255	345	425	4860	5600	7570	8150	5770 (76)	4540 (56)	110+	110*
Average		265	335	410	4590	6000	7490	8600	6350 (85)	4890 (58)		
GROUP 4												
1552	534	375	445	485	5390	6670	9120	9160	7320 (80)	4920 (54)	71	121*
1508	396	350	390	460	5790	6130	5810	8980	6890 (119)	3480 (39)	113	122*
1548	519	425	475	465	6060	6680	8140	9410	6780 (83)	4550 (48)	101	107
1553	540	220	310	345	4870	5950	8360	8740	7070 (85)	2350 (27)	112	121
1550	528	245	355	425	4400	5930	7940	9180	7230 (91)	4720 (52)	98	120
1502	378	285	345	430	4800	6020	6820	9120	5480 (80)	3210 (35)	95	124
1627	664	240	295	400	4120	6700	6450	9650	6690 (104)	4630 (48)	109	99
1520	432	260	315	330	4120	5650	7890	8550	6290 (80)	3590 (42)	105	122
1536	486	235	325	370	3780	5650	6800	8230	6640 (98)	4960 (60)	79	95
1566	570	420	520	500	6920	7290	8190	8820	7120 (87)	3600 (41)	65	93
Average		305	380	420	4040	6270	7550	8980	6750 (91)	4000 (45)	95	

TABLE I.—*Continued*

Series Number	Cement Number	Strength Tests									Expansion Tests as of May 1, 1945	
		Tension Tests of Standard Briquets, psi.			Compression Tests of 2 by 4-in. Cylinders, psi.						Months Required for Cylinders Stored in 1 per cent Solutions to Increase in Length 0.01 in.[b]	
		Moist Closet			Tank Specimens				Medicine Lake Specimens[c]			
		3 days	7 days	28 days	7 days	28 days	1 yr.	5 yr.	1 yr.	5 yr.	$MgSO_4$	Na_2SO_4
GROUP 5												
1524	444....	430	420	445	5140	5890	7600	6520	5990 (79)	1570 (24)	90	105
1629	666....	455	445	485	6430	5830	6100	8580	6480 (106)	2480 (29)	91	99
1521	435....	240	325	365	3860	5220	6920	8740	5830 (84)	3070 (35)	105	97
1549	525....	305	380	410	5290	5910	8420	9580	7900 (94)	4720 (49)	65	55
1514	414....	265	375	395	5320	6780	7560	7930	6410 (85)	1290 (16)	87	107
1587	614....	240	320	440	4340	6010	8310	8080	5890 (71)	660 (8)	84	120+
1532	474....	325	380	415	5050	5690	7900	7840	7210 (91)	3410 (44)	55	57
1531	471 ..	280	335	395	4420	5080	8160	8000	6090 (75)	4220 (53)	53	56
1610	642....	420	485	495	6080	6350	7380	8410	5670 (77)	1730 (21)	91	88
1633	670....	325	415	495	5690	6460	6220	8400	6140 (99)	1810 (22)	72	85
Average......		330	390	435	5160	5920	7460	8210	6360 (86)	2500 (30)	79	
GROUP 6												
1567	590....	225	320	375	3750	4880	7260	7160	5890 (81)	2350 (33)	53	102
1564	564....	215	320	390	4120	5760	9240	8690	6570 (71)	2790 (32)	57	55
1541	498....	425	440	460	5720	6530	8440	8930	7390 (88)	2290 (26)	79	53
1594	624....	250	245	385	3980	5870	7030	8310	6300 (90)	2430 (29)	51	113
1512	408....	310	375	455	4800	6590	7200	7170	6040 (84)	2700 (38)	46	60
1504	384....	255	350	405	4440	6300	7260	8680	6120 (84)	2640 (30)	60	43
1558	546....	275	345	395	5030	6120	8890	8180	5920 (67)	2180 (27)	55	49
1545	510....	245	350	415	4200	5230	8110	7970	7160 (88)	1960 (25)	54	51
1555	462....	320	370	425	4770	7100	9310	10030	7880 (85)	1710 (17)	51	55
1614	679....	420	470	465	6240	6890	6610	9100	4890 (74)	410 (5)	50	66
Average......		295	360	415	4710	6130	7940	8420	6420 (81)	2150 (26)	56	65
GROUP 7												
1562	558....	260	350	405	4160	6000	8040	9100	6710 (83)	1570 (17)	54	51
1624	659....	270	330	430	4390	6490	6910	8640	6070 (88)	1160 (13)	57	52
1570	573....	280	370	385	4270	6190	8000	9420	6540 (82)	1420 (15)	50	54
1630	667....	300	355	420	5060	7170	7190	8770	6520 (91)	0	60	56
1638	682....	265	255	370	5140	5230	5980	7460	4560 (76)	1860 (25)	50	49
1527	453....	265	360	400	4920	5920	6570	8450	5500 (84)	1320 (16)	53	46
1509	399....	295	350	390	4650	5840	6630	8130	8290 (125)	1020 (13)	48	46
1565	567....	335	380	410	5240	6430	8370	8200	6850 (82)	550 (7)	45	48
1522	438....	255	345	405	4260	5520	6400	7860	5750 (90)	0	46	53
1561	555....	325	405	425	5960	6980	8410	8120	6270 (75)	0	54	39
Average......		285	350	405	4810	6180	7250	8420	6310 (88)	890 (11)	52	49
GROUP 8												
1581	599....	290	340	405	5450	6120	6610	6620	5630 (85)	0	41	48
1559	549....	370	410	375	5360	6940	7620	7870	5670 (74)	0	44	47
1510	402....	240	370	405	4850	6180	7430	9030	5270 (71)	0	49	42
1622	653....	285	370	425	5250	6340	7660	7700	5720 (75)	0	55	45
1557	465....	290	355	375	4450	5860	8740	9500	6590 (75)	0	48	41
1539	501....	290	375	400	5610	6890	7880	8860	6700 (85)	0	47	37
1538	492....	315	365	440	4930	6480	7880	8180	5900 (75)	0	47	44
1591	619....	280	345	400	3760	4720	7460	8120	6030 (81)	0	43	41
1529	459....	320	400	405	5430	6350	7210	8590	5970 (83)	0	41	43
1517	423....	255	355	420	4140	5320	6410	8610	5010 (78)	0	38	40
Average......		295	370	405	4920	6120	7490	8310	5850 (78)	0	46	43
GROUP 9												
1540	495....	260	315	355	4500	5950	8190	8910	5720 (70)	0	42	27
1533	477....	260	355	385	5280	6260	8050	8910	6150 (76)	0	37	27
1597	629....	385	490	505	5930	8730	9100	8090	6380 (70)	0	34	37
1526	450....	370	420	440	4600	4910	6160	7140	4200 (68)	0	35	29

TABLE I.—*Concluded*

Series Number	Cement Number	Strength Tests									Expansion Tests as of May 1, 1945	
		Tension Tests of Standard Briquets, psi.			Compression Tests of 2 by 4-in. Cylinders, psi.						Months Required for Cylinders Stored in 1 per cent Solutions to Increase in Length 0.01 in.[b]	
		Moist Closet			Tank Specimens				Medicine Lake Specimens[c]			
		3 days	7 days	28 days	7 days	28 days	1 yr.	5 yr.	1 yr.	5 yr.	$MgSO_4$	Na_2SO_4
GROUP 9—*Continued*												
1556	552	435	505	445	5490	7320	7810	8010	5060 (65)	0	37	26
1516	420	380	410	430	5770	6410	7220	7700	4710 (65)	0	35	34
1626	663	230	360	415	4420	5780	5960	7140	5420 (92)	0	31	24
1525	447	280	360	385	5060	6020	7370	8690	5190 (70)	0	30	29
1632	669	320	410	435	5370	6200	7500	7460	4630 (62)	0	33	27
1588	615	250	305	405	4270	5580	7690	7510	4460 (58)	0	30	41
Average		315	395	420	5070	6320	7510	7960	5190 (70)	0	34	30
GROUP 10												
1592	620	310	365	435	4980	6270	7340	8170	5540 (75)	0	28	27
1590	618	340	400	440	5660	6560	8430	7680	6280 (74)	0	25	31
1595	627	270	310	425	4190	5860	8130	8240	6340 (78)	0	27	18
1528	456	340	380	395	5820	6270	7050	7940	4310 (61)	0	30	26
1542	504	265	340	420	4290	5330	8030	9970	5150 (64)	0	29	17
1618	645	320	345	390	5330	6470	5670	7300	4740 (84)	0	26	26
1609	641	330	430	455	4770	6690	6670	7770	4910 (74)	0	35	20
1623	656	285	350	385	5050	5550	6960	8030	5040 (72)	0	32	20
1582	602	270	330	405	5220	6090	6680	8510	5510 (82)	0	23	24
1621	650	235	315	355	4770	6100	6780	7860	4890 (72)	0	27	21
Average		295	355	410	5010	6120	7170	8150	5270 (74)	0	28	23
GROUP 11												
1573	594	305	350	470	3600	4520	7580	7230	2450 (32)	0	29	28
1617	644	250	335	370	4150	6480	6280	7490	4150 (66)	0	24	22
1500	372	260	310	410	4060	5340	7680	8440	4760 (62)	0	32	17
1575	579	255	325	420	5070	6370	8140	8760	5820 (71)	0	21	21
1560	537	235	345	355	4180	5880	7430	7660	4700 (63)	0	31	16
1641	685	335	375	355	4500	5420	5990	7570	5810 (97)	0	25	17
1574	595	255	305	350	3970	3990	5600	5530	3320 (59)	0	30	21
1513	411	250	340	380	5000	6010	6540	6800	4770 (73)	0	27	16
1501	375	290	375	410	5640	5960	7290	8070	4060 (56)	0	29	14
1631	668	260	335	420	4510	5560	6070	7800	4420 (73)	0	21	14
Average		270	340	395	4470	5550	6860	7540	4430 (65)	0	27	19
GROUP 12												
1534	480	330	375	425	5490	6620	8650	7460	5360 (62)	0	23	14
1544	522	305	390	405	5350	5710	7440	8570	4860 (65)	0	24	12
1515	417	275	345	350	5700	5330	7100	7140	3700 (52)	0	23	14
1600	632	300	390	420	4880	5560	7970	7590	3710 (47)	0	23	13
1519	429	350	370	380	4530	5820	7830	8770	2660 (34)	0	19	13
1572	593	275	360	425	4700	5670	7350	7900	3080 (42)	0	16	12
1530	468	285	325	360	4260	5020	6860	8040	2990 (44)	0	16	10
1615	680	295	380	420	4950	6710	7090	7140	4860 (69)	0	11	10
1598	630	240	305	355	3870	5180	7540	7760	3430 (45)	0	15	10
1625	662	265	380	410	4380	6370	6700	7990	2700 (40)	0	12	11
1535	483	255	295	395	4070	5210	7040	7750	1990 (28)	0	16	10
Average		290	355	395	4740	5750	7420	7830	3580 (48)	0	18	12

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[a] The expansions on which the order of resistance was partly determined for the cements of this table were those of cylinders after exposures that averaged about 5 yr., whereas, the expansions now shown are after exposures that have averaged about 10 yr. Rearrangement on the basis of the 10-yr. tests would somewhat modify this order but would not appreciably change the picture as a whole.

[b] A plus (+) sign following a number indicates that none of the 5 cylinders of that series had increased in length by as much as 0.01 in. while an asterisk (*) indicates that one or more cylinders had expanded 0.01 in. but that the average for the series will exceed the months indicated.

[c] Figures in parentheses indicate per cent of normal strength of the Medicine Lake cylinders based on parallel tests of cylinders from the same batches stored in tap water.

TABLE II.—OXIDE ANALYSES, CALCULATED COMPOUNDS, AND FINENESS DETERMINATIONS OF 121 COMMERCIAL CEMENTS TESTED FOR SULFATE RESISTANCE.

The 121 cements in the 12 groups are arranged in descending order of resistance as recorded in Table I.

Oxide analyses and fineness determinations were made during 1935 to 1937 for the Bureau of Agricultural Engineering of the U. S. Department of Agriculture by the National Bureau of Standards.

T indicates a trace.

Series Number	Cement Number	Loss on Ignition, per cent	Oxide Analyses, per cent												Insoluble Residue, per cent	Free Lime (CaO), per cent	Ratio		Percentage Retained on		Surface Area, sq. cm. per g.	Calculated Compounds, per cent					
			SiO_2	Fe_2O_3	FeO	TiO_2	P_2O_5	Mn_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	SO_3			Fe_2O_3 to Al_2O_3	Al_2O_3 to Fe_2O_3	No. 200 Sieve	No. 325 Sieve		C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	Sum of C_3A and C_4AF
GROUP 1																											
1584	611	1.2	22.5	3.7	0.02	0.25	0.17	0.06	4.4	64.1	1.4	0.28	0.51	1.7	0.06	0.4	0.84	1.19	4.9	13.6	1490	48.4	28.1	5.4	11.3	2.9	16.7
1599	631	1.4	20.4	4.8	0.00	0.63	0.10	0.08	4.3	63.8	1.9	0.36	0.20	1.9	0.10	0.3	1.12	0.90	5.4	12.1	1450	62.2	11.7	3.3	14.6	3.2	17.9
1551	531	1.2	23.2	4.5	T	0.19	0.12	0.13	4.2	62.1	2.4	0.16	0.26	1.7	0.12	0.1	1.07	0.93	12.5	23.6	1450	36.4	39.1	3.5	13.7	2.9	17.2
1511	405	2.2	22.3	2.9	T	0.24	0.12	0.10	3.8	63.7	2.3	0.15	0.51	1.7	0.20	1.1	0.76	1.31	4.5	12.5	1630	50.7	25.8	5.1	8.8	2.9	13.9
1568	591	1.4	19.9	5.2	0.02	0.25	0.11	0.06	4.8	63.8	1.8	1.20	0.02	1.8	0.12	0.9	1.08	0.92	8.5	20.3	1470	59.9	11.9	3.9	15.8	3.1	19.9
1571	576	1.3	23.6	3.9	T	0.20	0.06	0.01	3.9	63.0	2.2	0.20	0.51	1.4	0.20	0.8	1.00	1.00	10.5	21.6	1380	37.9	39.1	3.7	11.9	2.4	15.6
1518	426	1.1	22.8	3.5	0.00	0.23	0.19	0.47	3.8	63.0	2.6	0.19	0.44	1.8	0.15	0.4	0.92	1.09	2.6	8.0	1750	45.7	31.0	4.1	10.6	3.1	14.7
1620	647	1.4	23.2	3.5	0.04	0.28	0.30	0.06	4.2	63.2	1.7	0.21	0.37	1.6	0.09	0.1	0.83	1.20	4.1	10.8	1790	42.6	34.4	5.2	10.6	2.7	15.8
1596	628	1.1	21.8	5.2	0.02	0.22	0.29	0.05	2.8	65.3	1.2	0.67	0.13	1.7	0.14	1.3	1.86	0.54	3.5	10.6	1660	62.5	15.3	1.4[a]	13.4	2.9	....
1576	582	1.1	20.2	4.6	0.30	0.25	0.14	0.03	4.9	64.1	2.2	0.50	0.11	1.6	0.10	1.0	0.94	1.07	9.5	30.0	1160	59.2	13.4	5.2	14.0	2.7	19.2
Average		1.3	22.0	4.2	0.04	0.27	0.16	0.11	4.1	63.6	2.0	0.39	0.31	1.7	0.13	0.6	1.04	1.02	6.6	16.3	1520	50.6	25.0	4.4	12.5	2.9	16.8
GROUP 2																											
1580	596	1.9	22.8	2.0	0.01	0.22	0.07	0.15	3.8	65.9	1.6	0.19	0.23	1.6	0.28	0.9	0.53	1.90	5.0	12.9	1670	58.1	21.6	6.7	6.1	2.7	12.8
1505	387	1.1	22.9	2.8	T	0.26	0.03	0.04	3.9	65.5	1.1	0.19	0.41	1.9	0.05	0.8	0.72	1.39	4.3	10.0	1820	53.5	25.4	5.6	8.5	3.2	14.1
1593	621	3.5	22.0	5.4	0.09	0.22	0.13	0.03	4.4	58.2	3.3	0.44	0.67	1.8	0.06	0.1	1.23	0.82	4.4	11.6	1690	26.8	42.9	2.5	16.4	3.1	18.9
1506	390	1.2	22.4	3.0	T	0.21	0.07	0.09	3.9	63.2	3.6	0.25	0.50	1.9	0.17	1.4	0.77	1.30	2.0	14.0	1700	45.2	30.2	5.3	9.1	3.2	14.4
1543	507	1.4	22.2	4.0	T	0.15	0.08	0.06	3.4	62.3	4.1	0.11	0.33	1.8	0.08	0.6	1.18	0.85	2.7	7.4	1750	48.6	27.1	2.2	12.2	3.1	14.4
1583	605	1.0	21.6	5.0	0.00	0.24	0.10	0.07	4.3	62.1	3.3	0.25	0.73	1.8	0.12	0.1	1.16	0.86	3.3	8.4	1660	46.9	26.6	2.9	15.2	3.1	18.1
1563	561	4.1	20.8	2.9	0.25	0.34	0.37	0.08	4.2	62.2	2.2	0.44	0.18	1.9	0.36	1.0	0.69	1.45	3.4	6.7	2220	53.1	19.6	6.2	8.8	3.2	15.0
1507	393	1.4	21.7	3.1	T	0.25	0.05	0.10	3.6	63.0	3.9	0.31	0.39	2.3	0.17	0.7	0.86	1.16	2.2	5.8	2250	53.3	22.1	4.3	9.4	3.9	13.7
1537	489	0.9	21.5	4.6	T	0.28	0.04	0.07	4.8	63.4	1.9	0.20	0.69	1.6	0.13	0.2	0.96	1.04	3.6	10.9	1610	50.3	23.7	4.9	14.0	2.7	18.9
1554	543	1.8	21.1	4.2	T	0.24	0.13	0.07	4.2	63.9	2.3	0.15	0.28	1.7	0.12	1.3	1.00	1.00	7.0	14.1	1690	55.3	18.9	4.0	12.8	2.9	16.8
Average		1.8	21.9	3.7	0.04	0.24	0.11	0.08	4.1	63.0	2.7	0.25	0.44	1.8	0.15	0.7	0.91	1.18	3.8	10.2	1810	49.1	25.8	4.5	11.3	3.1	15.7
GROUP 3																											
1547	516	0.9	22.3	2.6	T	0.25	0.10	0.08	5.3	64.1	2.1	0.18	0.51	1.8	0.19	0.5	0.49	2.04	7.5	16.8	1520	44.7	30.3	9.7	7.9	3.1	17.6
1503	381	0.6	23.1	3.3	T	0.24	0.02	0.06	3.7	63.1	4.1	0.14	0.48	1.3	0.12	0.3	0.89	1.12	4.4	13.1	1650	46.6	31.2	4.2	10.0	2.2	14.2
1579	608	1.2	22.9	3.7	0.01	0.23	0.07	0.07	4.5	63.8	1.3	0.26	0.68	1.4	0.06	0.3	0.82	1.22	4.2	12.4	1560	44.8	31.9	5.6	11.3	2.4	16.9
1546	513	1.7	20.0	6.0	0.05	0.22	0.20	0.04	4.1	59.9	5.4	0.53	0.29	1.7	0.16	0.4	1.46	0.68	6.5	12.3	1910	49.2	20.3	0.7	18.2	2.9	18.9
1523	441	1.7	21.1	3.0	0.00	0.28	0.14	0.11	4.6	64.3	2.2	0.39	0.40	1.8	0.18	0.7	0.65	1.53	8.4	16.9	1480	58.0	16.8	7.1	9.1	3.1	16.2
1637	681	2.5	22.4	3.5	0.03	0.23	0.17	T	4.2	63.4	1.3	0.09	0.33	1.7	0.45	1.3	0.83	1.20	5.1	12.2	1770	44.3	30.9	5.2	10.6	2.9	15.8
1628	665	1.0	21.6	3.9	0.03	0.21	0.13	0.04	4.7	63.4	2.6	0.28	0.39	1.7	0.06	0.1	0.83	1.20	1.9	8.8	1720	51.4	23.2	5.8	11.9	2.9	17.7
1619	646	1.2	22.5	3.7	0.03	0.24	0.23	0.06	4.4	63.6	1.8	0.22	0.43	1.6	0.17	0.5	0.84	1.19	5.5	12.3	1970	46.3	29.7	5.4	11.3	2.7	16.7
1639	683	1.4	21.2	3.8	0.02	0.28	0.24	0.07	4.3	64.4	1.7	0.26	0.65	1.6	0.06	2.1	0.88	1.13	7.0	13.3	1700	53.4	20.6	5.0	11.6	2.7	16.6
1616	643	1.1	22.6	2.7	0.06	0.28	0.05	0.05	4.2	64.2	2.3	0.38	0.42	1.8	0.20	1.2	0.64	1.55	6.8	15.4	1510	47.1	29.3	6.6	8.2	3.1	14.8
Average		1.3	22.0	3.6	0.02	0.25	0.14	0.06	4.4	63.4	2.5	0.27	0.40	1.6	0.17	0.7	0.83	1.29	5.7	13.4	1680	[illegible]	[illegible]	5.5	[illegible]	[illegible]	[illegible]
GROUP 4																											
1552	534	1.5	21.7	2.0	0.04	0.19	0.09	0.04	3.8	66.2	2.4	0.09	0.12	2.1	0.10	0.5	0.53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

GROUP 4																											
1552	534....	1.5	21.7	2.0	0.04	0.19	0.09	0.04	3.8	66.2	2.4	0.00	0.12	2.1	0.10	0.5	0.53	1.90	3.7	3.9	2560	67.9	11.0	6.7	6.1	3.6	12.8
1508	396....	1.0	21.3	4.0	0.07	0.30	0.03	0.06	4.6	62.6	3.2	0.36	0.75	2.0	0.07	0.1	0.87	1.15	2.9	8.9	1880	50.1	23.4	5.4	12.2	3.4	17.6
1548	519....	1.3	19.8	2.9	T	0.24	0.09	0.10	4.7	65.0	3.2	0.13	0.23	2.5	0.17	0.8	0.62	1.62	2.7	5.1	2530	67.9	5.6	7.5	8.8	4.3	16.3
1553	540....	2.4	21.7	2.3	T	0.22	0.18	0.07	4.2	65.0	1.9	0.12	0.35	1.6	0.11	1.5	0.55	1.83	8.1	16.3	1660	57.3	19.1	7.2	7.0	2.7	14.2
1550	528....	2.6	22.0	2.6	0.03	0.19	0.07	0.05	4.2	63.6	2.9	0.12	0.16	1.5	0.23	1.2	0.62	1.62	6.1	12.6	1750	50.4	25.1	6.7	7.9	2.6	14.6
1502	378....	2.3	20.5	2.2	0.03	0.25	0.03	0.05	4.7	62.6	4.8	0.40	0.72	1.6	0.35	1.8	0.47	2.14	1.4	13.7	1500	52.2	19.5	8.7	6.7	2.7	15.4
1627	664....	0.8	22.4	4.6	0.03	0.24	0.18	0.05	5.2	61.2	2.6	0.36	0.60	2.0	0.03	0.3	0.88	1.13	2.1	8.4	1690	30.3	41.5	6.0	14.0	3.4	20.0
1520	432....	2.4	20.4	3.0	T	0.25	0.21	0.30	4.7	63.6	2.8	0.41	0.51	2.0	0.15	2.2	0.64	1.57	5.5	14.7	1610	53.2	18.5	7.4	9.1	3.4	16.5
1536	486....	1.5	21.4	3.0	T	0.31	0.05	0.05	5.3	64.1	2.1	0.11	0.63	1.5	0.37	0.4	0.57	1.77	4.3	11.9	1540	52.3	22.0	9.0	9.1	2.6	18.1
1566	570....	1.9	19.0	3.6	T	0.28	0.18	0.28	6.2	65.0	1.0	0.29	0.32	2.4	0.08	0.5	0.58	1.72	0.3	0.6	2280	64.4	6.0	10.3	10.9	4.1	21.2
Average		1.8	21.0	3.0	0.02	0.25	0.11	0.11	4.8	63.9	2.7	0.23	0.44	1.9	0.17	0.9	0.63	1.65	3.7	9.6	1900	54.6	19.2	7.5	9.2	3.3	16.7
GROUP 5																											
1524	444....	1.7	20.4	2.9	T	0.30	0.14	0.11	4.6	65.4	2.2	0.48	0.27	1.7	0.14	0.9	0.63	1.59	0.7	2.2	2360	67.5	7.7	7.3	8.8	2.9	16.1
1629	666....	1.3	20.4	3.6	T	0.18	0.10	0.03	4.3	65.0	2.7	0.31	0.23	2.2	0.10	1.4	0.84	1.19	0.1	0.2	2520	63.4	10.8	5.3	10.9	3.7	16.2
1521	435....	1.8	20.9	2.2	T	0.64	0.09	0.04	5.0	64.5	3.0	0.32	0.23	1.7	0.19	2.2	0.44	2.28	3.6	17.9	1590	53.0	20.0	9.5	6.7	2.9	16.2
1549	525....	1.3	20.9	2.7	0.16	0.27	0.29	0.14	5.4	63.3	3.0	0.06	0.52	1.9	0.42	0.9	0.50	2.00	3.1	6.3	1930	49.4	22.7	9.7	8.2	3.2	17.9
1514	414....	1.5	21.8	2.6	T	0.29	0.10	0.07	5.3	65.0	1.2	0.11	0.47	1.8	0.08	1.3	0.49	2.04	9.7	19.4	1590	49.0	25.6	9.6	7.9	3.1	17.5
1587	614....	3.0	23.6	0.4	0.00	0.22	0.00	T	3.6	66.3	1.0	0.00	0.20	2.0	0.14	3.0	b	b	1.8	6.1	2140	47.6	31.8	8.9	1.2	3.4	10.1
1532	474....	2.2	20.8	3.1	T	0.29	0.19	0.15	5.6	63.7	1.4	0.04	0.41	2.0	0.14	0.9	0.55	1.81	3.4	8.8	1830	49.6	22.3	9.6	9.4	3.4	19.0
1531	471....	1.1	20.9	5.0	T	0.25	0.16	0.05	5.0	61.4	2.8	0.07	1.22	1.8	0.09	0.5	1.00	1.00	5.8	14.0	1700	43.1	27.5	4.8	15.2	3.1	20.0
1610	642....	1.7	20.2	2.2	T	0.21	0.17	0.04	5.3	65.6	0.7	0.24	0.52	2.8	0.32	0.9	0.42	2.41	2.5	5.4	2260	63.0	10.5	10.3	6.7	4.8	17.0
1633	670....	1.7	21.6	2.8	T	0.30	0.11	0.04	4.3	63.0	4.1	0.18	0.37	1.9	0.15	1.2	0.65	1.54	0.6	2.5	2230	48.9	25.1	6.7	8.5	3.2	15.2
Average		1.7	21.2	2.8	0.02	0.30	0.14	0.07	4.8	64.3	2.2	0.18	0.44	2.0	0.18	1.3	0.61	1.76	3.1	8.3	2020	53.5	20.4	8.2	8.4	3.4	16.5
GROUP 6																											
1567	590....	2.1	21.4	2.6	0.02	0.26	0.12	0.06	5.3	63.9	1.7	1.20	0.02	1.7	0.26	0.7	0.49	2.04	6.0	16.9	1430	50.2	23.5	9.7	7.9	2.9	17.6
1564	564....	1.3	22.0	3.5	T	0.22	0.03	0.55	4.5	64.5	1.7	0.23	0.18	1.6	0.12	0.2	0.78	1.29	4.4	12.7	1640	54.6	22.0	6.0	10.6	2.7	16.6
1541	498....	1.6	20.2	3.2	T	0.24	0.20	0.25	5.5	63.2	2.2	0.23	0.62	2.5	0.10	0.8	0.58	1.72	1.0	1.3	2600	51.7	19.0	9.1	9.7	4.3	18.8
1594	624....	1.7	21.2	2.7	0.01	0.33	0.01	0.04	4.9	62.1	4.2	0.10	0.77	2.0	0.26	1.1	0.55	1.82	8.5	17.4	1750	44.6	27.2	8.4	8.2	3.4	16.6
1512	408....	1.9	20.0	5.5	0.00	0.30	T	0.69	5.8	61.3	2.4	0.30	0.09	1.7	0.13	0.3	0.95	1.05	5.8	14.4	1880	44.6	23.8	6.0	16.7	2.9	22.7
1504	384....	1.7	21.6	2.4	T	0.23	0.02	0.09	5.2	62.9	3.3	0.16	0.59	1.8	0.15	0.7	0.46	2.17	6.9	17.5	1630	45.4	27.8	9.7	7.3	3.1	17.0
1558	546....	1.3	20.5	3.6	0.05	0.27	0.08	0.05	5.7	63.5	2.5	0.18	0.63	1.8	0.15	0.9	0.63	1.58	3.2	9.2	1640	50.3	20.9	9.0	10.9	3.1	19.9
1545	510....	1.1	22.1	2.3	T	0.19	0.24	0.04	4.7	62.4	4.6	0.49	0.28	1.8	0.26	0.6	0.49	2.04	5.5	13.6	1750	43.4	30.7	8.6	7.0	3.1	15.6
1555	462....	1.1	20.3	3.5	T	0.30	0.15	0.11	5.5	63.4	3.0	0.22	0.41	1.9	0.08	0.9	0.64	1.57	2.5	8.6	1490	52.6	18.6	8.6	10.6	3.2	19.2
1614	679....	1.3	19.7	2.9	0.14	0.29	0.12	0.06	4.6	64.7	3.3	0.15	0.39	2.7	1.30	0.7	0.63	1.59	1.1	1.9	2610	67.9	5.3	7.3	8.8	4.6	16.1
Average		1.5	20.9	3.2	0.02	0.26	0.10	0.19	5.2	63.2	2.9	0.33	0.40	2.0	0.16	0.7	0.62	1.69	4.5	11.4	1840	50.5	21.9	8.2	9.8	3.3	18.0
GROUP 7																											
1562	558....	1.4	22.5	2.3	T	0.24	0.12	0.05	5.1	64.5	1.8	0.44	0.27	1.5	0.15	0.9	0.45	2.22	9.2	19.8	1450	45.9	30.0	9.6	7.0	2.6	16.6
1624	659....	1.7	22.1	1.9	0.04	0.35	0.12	0.05	5.3	65.4	1.3	0.04	0.16	1.7	0.18	1.0	0.36	2.79	6.4	16.7	1720	50.9	25.1	10.8	5.8	2.9	16.6
1570	573....	1.9	22.2	1.8	T	0.24	0.05	0.02	5.2	63.8	2.4	0.37	0.61	1.8	0.28	1.2	0.35	2.88	4.7	19.6	1470	43.3	31.1	10.7	5.5	3.1	16.2
1630	667....	1.1	21.9	2.7	T	0.31	0.18	0.07	5.5	64.2	1.6	0.21	0.52	1.9	0.17	1.1	0.49	2.04	5.4	13.5	1810	44.0	29.6	10.0	8.2	3.2	18.2
1638	682....	1.4	20.0	4.4	T	0.23	0.10	0.07	4.3	62.7	4.8	0.18	0.40	1.7	0.09	1.4	1.02	0.98	6.8	13.4	2160	57.4	14.1	3.9	13.4	2.9	17.3
1527	453....	1.5	20.9	3.5	T	0.27	0.34	0.17	4.8	66.0	0.7	0.11	0.51	1.5	0.12	2.4	0.73	1.37	5.2	13.3	1500	58.4	15.9	6.8	10.6	2.6	17.4
1509	399....	1.1	21.6	2.5	T	0.32	0.02	0.06	5.0	62.7	4.1	0.25	0.77	1.9	0.07	0.5	0.50	2.00	8.0	17.0	1500	46.3	27.1	9.0	7.6	3.2	16.6
1565	567....	1.5	20.4	3.4	0.00	0.32	0.22	0.19	6.3	64.6	0.9	0.23	0.59	1.7	0.07	0.5	0.54	1.85	4.2	12.2	1470	53.7	18.0	10.9	10.3	2.9	21.2
1522	438....	1.0	21.5	2.8	0.04	0.29	0.22	0.09	5.3	63.9	2.5	0.40	0.69	1.7	0.04	0.7	0.53	1.89	5.3	16.0	1440	49.3	24.6	9.3	8.5	2.9	17.8
1561	555....	0.9	20.5	3.1	T	0.25	0.17	0.02	6.1	66.0	0.9	0.14	0.34	1.7	0.11	0.6	0.51	1.97	8.5	18.8	1620	60.0	13.6	10.9	9.4	2.9	20.3
Average		1.4	21.4	2.8	0.01	0.28	0.15	0.08	5.3	64.4	2.1	0.24	0.49	1.7	0.13	1.0	0.55	2.00	6.4	16.0	1610	50.9	22.9	9.2	8.6	2.9	17.8

TABLE II.—*Concluded*

Series Number	Cement Number	Loss on Ignition, per cent	Oxide Analyses, per cent												Insoluble Residue, per cent	Free Lime (CaO), per cent	Ratio		Percentage Retained on		Surface Area, sq. cm. per g.	Calculated Compounds, per cent					
			SiO_2	Fe_2O_3	FeO	TiO_2	P_2O_5	Mn_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	SO_2			Fe_2O_3 to Al_2O_3	Al_2O_3 to Fe_2O_3	No. 200 Sieve	No. 325 Sieve		C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	Sum of C_3A and C_4AF
GROUP 8																											
1581	599....	1.9	22.3	2.0	0.01	0.23	0.12	0.13	3.7	67.0	2.0	0.19	0.12	0.06	1.0	1.0	0.54	1.85	2.0	4.1	2470	71.1	10.4	6.4	6.1	0.1	12.5
1559	549....	1.8	19.5	3.4	T	0.27	0.09	0.04	5.6	64.0	2.3	0.36	0.61	2.3	0.09	1.9	0.61	1.65	0.6	0.4	2780	55.5	14.1	9.1	10.3	3.9	19.4
1510	402....	1.2	22.5	2.4	T	0.27	0.03	0.07	4.8	62.1	3.7	1.04	0.54	1.8	0.06	0.7	0.50	2.00	9.1	18.4	1530	37.9	36.0	8.6	7.3	3.1	15.9
1622	653....	1.5	21.1	2.3	0.01	0.23	0.04	0.06	5.1	64.2	3.3	0.04	0.26	1.7	0.16	1.2	0.45	2.22	2.7	8.4	1830	44.2	29.5	9.6	7.0	2.9	16.6
1557	465....	1.3	20.8	2.9	T	0.31	0.14	0.21	5.8	64.1	1.9	0.43	0.61	1.8	0.13	1.1	0.50	2.00	7.8	18.4	1420	50.0	22.0	10.4	8.8	3.1	19.2
1539	501....	1.7	19.4	3.5	0.09	0.24	0.34	0.23	6.4	63.9	0.9	0.05	0.64	2.4	0.11	1.3	0.55	1.83	7.0	14.2	1630	52.4	16.1	11.0	10.6	4.1	21.6
1538	492....	1.2	22.4	1.9	T	0.27	0.03	0.05	4.9	65.4	1.3	0.27	0.76	1.5	0.14	0.9	0.39	2.58	5.5	13.9	1650	52.2	24.9	9.8	5.8	2.6	15.6
1591	619....	2.1	22.3	2.0	0.01	0.26	0.09	0.03	4.9	62.8	2.6	0.52	0.50	1.9	0.13	0.5	0.41	2.45	9.5	19.5	1380	42.7	31.8	9.6	6.1	3.2	15.7
1529	459....	2.0	20.5	3.4	T	0.27	0.31	0.16	4.7	65.5	0.7	0.25	0.47	1.6	0.14	2.4	0.72	1.38	2.3	3.1	2040	59.9	13.6	6.7	10.3	2.7	17.0
1517	423....	0.9	22.3	2.0	T	0.23	0.13	0.09	4.6	62.7	4.7	0.30	0.45	1.7	0.08	1.0	0.44	2.30	6.7	14.9	1590	42.9	31.7	8.8	6.1	2.9	14.7
Average		1.6	21.3	2.6	0.01	0.26	0.13	0.11	5.1	64.2	2.3	0.35	0.50	1.7	0.20	1.2	0.51	2.03	5.3	11.5	1830	50.9	23.0	9.0	7.8	2.9	16.8
GROUP 9																											
1540	495....	1.0	20.4	3.2	T	0.24	0.19	0.24	5.7	64.1	2.4	0.42	0.60	1.7	0.07	1.5	0.56	1.78	6.5	17.2	1480	51.9	19.4	9.7	9.7	2.9	19.4
1533	477....	1.4	21.0	2.2	T	0.26	0.19	0.21	5.8	65.6	1.4	0.00	0.35	1.7	0.18	1.4	0.38	2.63	9.6	20.4	1650	54.6	19.1	11.9	6.7	2.9	18.6
1597	629....	1.4	19.0	2.4	0.03	0.27	0.27	0.09	5.9	64.0	3.4	0.23	0.53	2.6	0.06	0.8	0.41	2.46	0.1	3.3	2050	62.3	7.6	11.6	7.3	4.4	19.9
1526	450....	1.7	19.5	3.3	T	0.26	0.14	0.14	4.4	65.3	3.0	0.24	0.11	2.2	0.05	1.7	0.75	1.33	3.2	5.4	2460	70.0	3.2	6.1	10.0	3.7	16.1
1556	552....	1.9	19.4	3.5	0.00	0.28	0.11	0.11	5.4	63.8	2.9	0.21	0.37	2.1	0.16	1.3	0.65	1.54	0.3	1.4	2820	59.6	10.7	8.4	10.6	3.6	19.0
1516	420....	1.3	20.9	2.1	T	0.29	T	0.04	5.6	64.2	3.1	0.21	0.39	2.2	0.11	0.8	0.38	2.66	5.1	9.0	2480	52.1	20.7	11.3	6.4	3.7	17.7
1626	663....	1.4	21.9	2.2	0.04	0.26	0.21	0.06	5.2	63.7	2.9	0.21	0.37	1.7	0.11	1.0	0.42	2.36	3.5	11.6	1730	45.7	28.4	10.0	6.7	2.9	16.7
1525	447....	1.3	20.2	3.4	T	0.31	0.15	0.12	5.2	65.0	2.7	0.26	0.30	1.4	0.02	1.4	0.65	1.53	4.2	13.0	1600	61.5	11.6	8.0	10.3	2.4	18.3
1632	669....	1.4	20.2	2.4	0.07	0.26	0.29	0.07	6.0	63.5	3.7	0.29	0.45	1.9	0.24	0.4	0.40	2.50	5.1	11.1	1760	54.1	17.2	11.8	7.3	3.2	19.1
1588	615....	2.3	22.2	0.3	0.05	0.31	0.00	T	5.5	64.8	2.8	0.00	0.12	1.6	0.10	1.4	*b*	*b*	3.6	11.6	1920	47.2	28.1	14.1	0.9	2.7	15.0
Average		1.5	20.5	2.3	0.02	0.27	0.16	0.11	5.5	64.4	2.8	0.21	0.36	1.9	0.11	1.2	0.51	2.08	4.1	10.4	2000	55.9	16.6	10.3	7.6	3.2	18.0
GROUP 10																											
1592	620....	1.3	21.7	2.2	0.03	0.29	0.09	0.05	5.7	63.0	3.4	0.15	0.71	1.7	0.04	0.3	0.39	2.59	0.9	19.2	1490	43.8	29.2	11.4	6.7	2.9	18.1
1590	618....	1.2	20.3	2.8	0.16	0.34	0.06	0.08	6.9	63.2	2.7	0.17	0.41	1.8	0.08	0.3	0.41	2.46	5.5	12.5	1810	46.1	23.5	13.5	8.5	3.1	22.0
1595	627....	1.9	23.3	2.0	0.00	0.26	0.05	0.05	4.8	64.4	1.2	0.46	0.53	1.4	0.07	2.0	0.42	2.40	2.3	10.4	1810	37.6	38.5	9.3	6.1	2.4	15.4
1528	456....	2.3	20.7	3.5	T	0.26	0.31	0.17	4.8	65.1	0.7	0.29	0.54	1.5	0.13	2.4	0.73	1.37	2.9	3.2	2480	56.3	17.0	6.8	10.6	2.6	17.4
1542	504....	1.2	22.0	2.4	T	0.19	0.08	0.04	5.3	62.6	4.0	0.04	0.48	1.7	0.11	1.1	0.45	2.21	4.5	13.1	1470	39.1	33.6	10.0	7.3	2.9	17.3
1618	645....	2.0	20.0	3.1	0.45	0.24	0.06	0.03	5.2	63.0	3.1	0.29	0.61	1.9	0.14	2.2	0.60	1.68	5.5	11.3	2060	50.6	19.3	8.5	9.4	3.2	17.9
1609	641....	0.9	22.1	2.3	0.00	0.23	0.15	T	5.4	65.2	0.9	0.39	0.66	1.8	0.13	0.6	0.43	2.34	4.6	11.2	1720	50.1	25.6	10.4	7.0	3.1	17.4
1623	656....	1.4	20.8	2.4	0.01	0.29	0.03	0.06	5.5	63.1	3.7	0.04	0.90	1.8	0.19	1.4	0.44	2.29	8.5	17.6	1620	47.4	23.9	10.5	7.3	3.1	17.8
1582	602....	1.1	21.1	2.6	0.01	0.33	0.11	0.03	5.4	63.1	3.4	0.26	0.94	1.9	0.16	0.8	0.48	2.08	8.0	17.2	1400	47.6	24.6	9.9	7.9	3.2	17.8
1621	650....	1.4	21.5	2.4	0.00	0.25	0.02	0.03	5.7	64.1	2.3	0.14	0.57	1.6	0.07	2.0	0.42	2.38	12.0	23.0	1580	43.0	29.3	11.0	7.3	2.7	18.3
Average		1.5	21.4	2.6	0.07	0.27	0.10	0.05	5.5	63.7	2.5	0.22	0.64	1.7	0.11	1.3	0.48	2.18	5.5	13.9	1740	46.2	26.5	10.1	7.8	2.9	17.9

GROUP 11																							
1573	594....	2.0	23.6	2.1	0.12	0.28	0.17	T	6.2	61.3	1.3	0.33	0.43	2.6	2.6	0.9	0.34	2.95	6.8	17.6	1710	14.2	57.0	12.9	6.4	4.4	19.3
1617	644....	1.5	20.5	2.5	0.52	0.24	0.06	0.03	5.2	63.2	3.2	0.24	0.55	1.8	0.19	1.6	0.48	2.08	6.1	14.4	1720	51.1	20.3	9.5	7.6	3.1	17.1
1500	372....	1.6	21.3	2.6	T	0.23	0.03	0.08	6.4	64.4	1.4	0.12	0.64	1.5	0.25	1.0	0.41	2.46	14.2	23.3	1480	45.0	27.2	12.6	7.9	2.6	20.5
1575	579....	1.5	21.1	2.1	0.10	0.27	0.12	0.03	5.7	64.6	2.3	0.44	0.15	1.7	0.10	0.9	0.37	2.72	3.2	13.7	1540	52.6	20.9	11.6	6.4	2.9	18.0
1560	537....	1.4	20.1	3.6	0.09	0.31	0.12	0.06	6.2	63.1	2.0	0.72	0.47	1.9	0.10	0.9	0.58	1.72	10.3	20.0	1550	48.0	21.5	10.3	10.9	3.2	21.2
1641	685....	1.3	22.0	2.4	0.03	0.25	0.13	0.05	5.4	64.9	0.8	0.46	0.57	1.9	0.24	0.8	0.44	2.25	5.8	13.1	1530	48.4	26.6	10.2	7.3	3.2	17.5
1574	595....	1.9	21.9	2.1	0.19	0.27	0.15	T	6.1	63.8	1.3	0.34	0.50	1.6	0.07	1.5	0.34	2.90	6.3	19.5	1490	38.4	33.9	12.6	6.4	2.7	19.0
1513	411....	0.6	21.2	2.5	0.02	0.30	T	0.65	6.1	64.3	2.2	0.16	0.25	1.9	0.08	0.5	0.41	2.44	10.6	22.2	1450	48.5	24.3	11.9	7.6	3.2	19.5
1501	375....	1.3	20.8	2.3	T	0.27	0.04	0.03	5.6	64.4	2.8	0.35	0.44	1.8	0.17	1.5	0.41	2.43	5.9	15.5	1580	51.7	20.7	10.9	7.0	3.1	17.9
1631	668....	0.9	21.9	2.2	0.02	0.21	0.21	0.03	5.0	63.3	4.2	0.38	0.35	1.6	0.10	0.9	0.44	2.27	7.7	17.6	1470	46.1	28.1	9.5	6.7	2.7	16.2
Average		1.4	21.4	2.4	0.11	0.26	0.10	0.10	5.8	63.7	2.2	0.35	0.44	1.8	0.39	1.1	0.42	2.42	7.7	17.7	1550	44.4	28.1	11.2	7.4	3.1	18.6
GROUP 12																							
1534	480....	1.0	19.8	2.9	0.03	0.28	0.15	0.14	6.9	65.0	1.4	0.10	0.40	1.8	0.13	0.5	0.42	2.38	5.9	15.0	1720	56.3	14.4	13.4	8.8	3.1	22.2
1544	522....	1.7	21.2	2.2	0.05	0.28	0.05	0.11	5.8	65.7	1.1	0.33	0.23	1.5	0.17	1.4	0.38	2.64	7.1	14.3	1790	54.1	20.1	11.6	6.7	2.6	18.3
1515	417....	1.2	21.1	2.1	T	0.31	T	0.03	5.5	64.6	2.9	0.17	0.50	1.7	0.11	1.4	0.38	2.62	7.4	14.9	1730	51.9	21.4	11.0	6.4	2.9	17.4
1600	632....	1.4	21.5	2.5	0.00	0.29	0.03	0.16	5.9	64.6	1.1	0.46	0.46	1.8	0.10	1.1	0.42	2.36	7.0	15.4	1370	46.5	26.6	11.4	7.6	3.1	19.0
1519	429....	2.0	20.1	2.8	0.25	0.30	0.21	0.12	6.8	63.9	1.3	0.06	0.63	1.9	0.30	1.4	0.41	2.43	5.1	12.7	1810	46.4	22.7	13.3	8.5	3.2	21.8
1572	593....	1.7	21.5	2.2	0.07	0.30	0.19	T	6.6	64.3	1.4	0.20	0.37	1.7	0.08	1.0	0.33	3.00	7.4	18.4	1690	41.8	30.2	13.8	6.7	2.9	20.5
1530	468....	1.6	20.5	2.3	T	0.26	0.11	0.05	6.0	62.8	3.1	0.00	1.41	1.9	0.14	1.7	0.38	2.61	8.2	17.6	1550	43.7	25.9	12.0	7.0	3.2	19.0
1615	680....	1.3	19.8	2.2	0.15	0.29	0.36	0.10	6.5	63.7	3.1	0.40	0.59	1.8	0.15	0.9	0.34	2.95	9.7	20.1	1290	53.1	16.8	13.5	6.7	3.1	20.2
1598	630....	1.9	21.5	2.2	0.01	0.23	0.00	0.04	5.5	64.0	2.3	0.30	0.62	1.5	0.08	1.9	0.40	2.50	15.7	25.6	1200	44.8	27.9	10.8	6.7	2.6	17.5
1625	662....	1.6	19.5	2.7	0.18	0.37	0.05	T	7.1	63.3	2.8	0.04	0.66	1.8	0.22	1.7	0.38	2.63	4.3	14.7	1310	45.7	21.5	14.2	8.2	3.1	22.4
1535	483....	1.2	21.5	2.3	0.10	0.31	0.04	0.06	5.9	61.9	3.7	0.25	0.99	1.8	0.32	0.9	0.39	2.56	7.8	17.2	1550	36.7	34.1	11.7	7.0	3.1	18.7
Average		1.5	20.7	2.4	0.08	0.29	0.11	0.07	6.2	64.0	2.2	0.21	0.62	1.7	0.16	1.3	0.38	2.61	7.8	16.9	1550	47.4	23.8	12.4	7.3	3.0	19.7

[a] Value is for C$_2$F and is not included in average for C$_3$A.

[b] White cement. Ratio of Fe$_2$O$_3$ and Al$_2$O$_3$ not included in averages.

TABLE III.—LEAN MORTAR BAR TESTS MADE OF THE 121 CEMENTS OF TABLE I BY FOUR LABORATORIES IN STUDIES OF ACCEPTANCE TESTS FOR SULFATE RESISTANCE.

Columns are lettered at the top to facilitate comparison with data of Table V.

Cement Index Numbers	C_3A, per cent	Lean Mortar Bars, Mix 1:5								Lean Mortar Bars, Mix 1:6								
		Length Changes, per cent														Sonic Changes, per cent		
		Na_2SO_4		$MgSO_4$	Na_2SO_4		$MgSO_4$		Combination	Na_2SO_4	$MgSO_4$	Combination	Na_2SO_4	$MgSO_4$	Combination	$NaSO_4$	$MgSO_4$	Combination
		0.78*M*		0.78*M*	0.15*M*	0.50*M*	0.15*M*	0.50*M*	0.50*M*	0.15*M*	0.15*M*	0.50*M*	0.15*M*	0.15*M*	0.50*M*	0.15*M*	0.15*M*	0.50*M*
		21 days	21 days	21 days	28 days	28 days	28 days	28 days	28 days	28 days	28 days	14 days	28 days	28 days	14 days	28 days	28 days	7 days
		NBS	UF	UF	UF	UF	UF	UF	UF	CPCC	CPCC	CPCC	PCA	PCA	PCA	PCA	PCA	PCA
		(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)
									GROUP 1									
611 103....	5.4	0.03	0.02	0.03	0.01	0.02	0.01	0.03	0.03	0.01	0.01	0.11	0.03	0.14	0.70	37	17	−10
631 29....	3.3	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.03	0.01	0.70	1.06	0.02	0.03	0.28	24	25	23
531 19....	3.5	0.02	0.02	0.08	0.01	0.03	0.01	0.02	0.03	0.02	0.03	0.63	0.02	0.16	0.33	40	38	35
405 57....	5.1	0.01	0.02	0.06	0.01	0.01	0.01	0.02	0.03	0.02	0.06	0.15	0.03	0.03	0.16	4	24	24
591 24....	3.9	0.03	0.02	0.08	0.01	0.03	0.01	0.04	0.10	0.06	0.41	0.68	0.12	0.32	0.76	7	−17	−14
576 22....	3.7	0.03	0.04	0.17	0.02	0.04	0.02	0.12	0.07	0.01	0.58	0.53	0.04	0.17	0.38	49	38	20
426 63....	4.1	0.02	0.02	0.20	0.02	0.08	0.02	0.23	0.21	0.03	0.02	0.17	0.06	0.35	F[b]	21	−9	−23
647 117....	5.2	0.02	0.03	0.08	0.02	0.04	0.02	0.05	0.04	0.02	0.10	0.21	0.00	0.10	0.62	28	36	10
628 28....	1.4[a]	0.03	0.02	0.09	0.01	0.03	0.01	0.08	0.23	0.01	0.72	1.01	0.09	0.13	0.67	−3	19	6
582 23....	5.2	0.03	0.04	0.46	0.02	0.04	0.02	0.31	0.22	0.06	0.51	0.89	0.16	0.54	1.31	2	−8	−11
Average....	4.4	0.02	0.02	0.13	0.01	0.03	0.01	0.09	0.13	0.03	0.31	0.54	0.06	0.20	....	21	18	8
									GROUP 2									
596 100....	6.7	0.05	0.05	0.10	0.02	0.09	0.02	0.09	0.16	0.02	0.03	0.43	0.14	0.32	0.84	4	−16	−15
387 53....	5.6	0.04	0.04	0.06	0.03	0.23	0.02	0.10	0.28	0.17	0.32	0.56	0.22	0.29	1.01	−23	−36	−27
621 27....	2.5	0.03	0.03	0.05	0.01	0.03	0.01	0.04	0.03	0.03	0.50	0.58	0.04	0.29	0.15	73	48	64
390 54....	5.3	0.03	0.03	0.03	0.02	0.05	0.02	0.12	0.07	0.10	0.41	0.44	0.07	0.63	0.95	25	−40	−15
507 17....	2.2	0.03	0.02	0.04	0.02	0.03	0.02	0.04	0.04	0.02	0.06	0.43	0.06	0.47	1.07	20	−17	−12
605 26....	2.9	0.03	0.03	0.03	0.02	0.04	0.02	0.04	0.03	0.03	0.51	0.78	0.06	0.09	0.50	10	25	−1
561 93....	6.2	0.04	0.02	0.02	0.02	0.07	0.01	0.03	0.04	0.02	0.02	0.06	0.05	0.05	0.56	29	15	−8
393 33....	4.3	0.03	0.02	0.01	0.01	0.04	0.02	0.03	0.02	0.05	0.64	0.36	0.13	0.42	0.76	−7	−25	−19
489 16....	4.9	0.04	0.03	0.02	0.01	0.03	0.02	0.03	0.04	0.03	0.09	0.53	0.09	0.25	0.73	5	−14	−15
543 20....	4.0	0.12	0.04	0.11	0.01	0.04	0.02	0.04	0.11	0.06	0.20	0.16	0.05	0.12	0.69	12	17	−6
Average....	4.5	0.04	0.03	0.05	0.02	0.07	0.02	0.06	0.08	0.05	0.28	0.43	0.09	0.29	0.73	15	−4	−5

GROUP 3																		
516	84....	9.7	0.06	0.11	0.09	0.04	0.66	0.04	0.34	0.22	0.18	0.08	0.03	0.58	0.42	F	−28	−16	−27
381	12....	4.2	0.02	0.03	0.11	0.02	0.09	0.02	0.22	0.24	0.06	0.44	0.49	0.07	0.36	0.72	26	−3	−17
608	102....	5.6	0.03	0.02	0.02	0.01	0.06	0.01	0.03	0.08	0.05	0.07	0.20	0.13	0.35	F	17	−16	−26
513	18....	0.7	0.03	0.02	0.05	0.01	0.03	0.01	0.02	0.06	0.02	0.15	0.52	0.02	0.22	0.67	29	6	−10
441	68....	7.1	0.04	0.04	0.03	0.01	0.05	0.01	0.03	0.05	0.03	0.05	0.10	0.15	0.30	0.83	6	−11	−19
681	129....	5.2	0.04	0.03	0.07	0.01	0.08	0.01	0.07	0.09	0.03	0.03	0.30	F	F	F	18	14	F
665	32....	5.8	0.03	0.03	0.02	0.02	0.14	0.01	0.06	0.21	0.11	0.45	0.45	0.21	F	0.79	−12	−15	−18
646	116....	5.4	0.03	0.03	0.06	0.01	0.10	0.01	0.06	0.19	0.04	0.07	0.16	0.17	0.21	F	−12	15	−27
683	131....	5.0	0.07	0.04	0.06	0.02	0.32	0.02	0.25	0.39	0.03	0.06	0.23						
643	114....	6.6	0.07	0.11	0.41	0.07	0.40	0.03	0.51	0.64	0.77	0.53	0.63	0.66	0.54	F	−44	−34	−29
Average....		5.5	0.04	0.05	0.09	0.02	0.19	0.02	0.16	0.22	0.13	0.19	0.31	0.23+	0.33+	....	0	−6	−21
GROUP 4																		
534	40....	6.7	0.05	0.09	0.01	0.03	0.13	0.03	0.03	0.10	0.24	0.77	1.01	0.20	0.23	0.73	−24	−17	−18
396	13....	5.4	0.02	0.03	0.05	0.02	0.04	0.02	0.05	0.05	0.09	0.21	0.78	0.09	0.22	0.62	16	1	−4
519	39....	7.5	0.13	0.28	0.17	0.08	0.62	0.08	0.11	0.15	0.45	0.87	0.92	0.37	0.39	F	−31	−35	−40
540	89....	7.2	0.27	0.20	0.26	0.07	0.19	0.04	0.09	0.34	0.06	0.36	0.32	0.26	F	F	−13	F	−22
528	87....	6.7	0.14	0.03	0.03	0.02	0.06	0.02	0.04	0.13	0.03	0.02	0.13	0.16	0.25	0.84	0	1	−21
378	51....	8.7	0.06	0.07	0.02	0.03	0.16	0.03	0.05	0.21	0.25	0.40	0.45	0.41	0.43	0.87	−26	−34	−20
664	31....	6.0	0.02	0.03	0.14	0.03	0.06	0.03	0.18	0.12	0.25	0.21	0.14	0.15	0.20	0.42	32	43	11
432	65....	7.4	0.04	0.08	0.21	0.02	0.19	0.03	0.17	0.32	0.03	0.11	0.28	0.19	F	F	−9	F	−25
486	78....	9.0	0.50	0.03	0.03	0.02	0.03	0.01	0.02	0.04	0.05	0.06	0.05	0.08	0.19	0.54	8	−5	−15
570	43....	10.3	0.10	0.18	0.04	0.02	0.15	0.03	0.02	0.03	0.28	0.47	0.26	0.18	0.24	0.55	−5	−14	−3
Average....		7.5	0.13	0.10	0.10	0.03	0.16	0.03	0.08	0.15	0.17	0.35	0.43	0.21	0.32+	0.66+	−5	....	−16
GROUP 5																		
444	35....	7.3	0.09	0.04	0.01	0.02	0.06	0.02	0.02	0.02	0.39	0.62	0.77	0.44	0.22	0.84	−42	−27	−33
666	47....	5.3	0.12	0.04	0.03	0.02	0.20	0.02	0.07	0.12	0.39	0.77	1.14	0.34	0.39	F	−43	−40	−41
435	66....	9.5	0.10	0.07	0.17	0.03	0.20	0.03	0.15	0.19	0.20	0.18	0.05	0.54	F	F	−39	F	−32
525	86....	9.7	0.37	0.22	0.43	0.12	0.86	0.06	0.51	0.48	0.03	0.02	0.04	F	F	F	F	F	F
414	60....	9.6	0.11	0.16	0.13	0.06	0.62	0.04	0.26	0.50	0.16	0.45	0.26	0.63	0.49	F	−47	−29	−31
614	104....	8.9	0.38	0.15	0.36	0.09	0.83	0.05	0.38	0.51	0.80	0.32	0.93	0.43	0.49	F	−29	−26	−28
474	74....	9.6	0.11	0.06	0.02	0.02	0.17	0.01	0.02	0.05	0.05	0.13	0.02	0.26	0.34	0.67	5	−24	−26
471	15....	4,8	0.05	0.21	0.80	0.07	0.50	0.06	0.47	0.59	0.30	0.43	1.07	0.49	0.60	1.14	−35	−35	−34
642	46....	10.3	0.42	0.47	0.72	0.21	2.20	0.06	0.22	0.96	F	1.06	0.71	F	0.57	1.05	F	−44	−24
670	127....	6.7	0.10	0.07	0.04	0.03	0.20	0.02	0.04	0.08	0.05	0.04	0.23	F	F	0.94	−28	−11	−26
Average....		8.2	0.18	0.15	0.27	0.07	0.58	0.04	0.21	0.35	0.38+	0.40	0.52	0.47+	0.45+	....	....	....	....
GROUP 6																		
590	97....	9.7	0.12	0.10	0.04	0.04	0.33	0.03	0.09	0.38	0.18	0.16	0.65	0.36	0.26	0.87	−26	−11	−16
564	21....	6.0	0.06	0.03	0.09	0.02	0.05	0.01	0.10	0.07	0.04	0.39	1.22	0.09	0.10	0.59	14	20	−3
498	38....	9.1	0.31	0.18	0.31	0.08	0.77	0.04	0.06	0.28	0.21	0.52	0.53	0.51	0.57	F	−46	−45	−37
624	109....	8.4	0.05	0.06	0.03	0.03	0.21	0.02	0.08	0.14	0.19	0.38	0.21	0.35	0.45	F	−23	−27	−17
408	58....	6.0	0.03	0.05	0.22	0.02	0.11	0.03	0.15	0.24	0.05	0.31	0.23	0.10	0.13	0.36	20	25	9
384	52....	9.7	0.07	0.07	0.09	0.03	0.17	0.03	0.11	0.23	0.76	0.53	0.81	0.15	0.28	0.42	11	2	5
546	90....	9.0	0.14	0.10	0.25	0.10	0.36	0.04	0.15	0.41	0.10	0.10	0.47	0.71	0.46	F	−53	−29	−40
510	83....	8.6	0.09	0.11	0.19	0.08	0.65	0.04	0.22	0.75	0.80	0.29	0.31	F	F	F	F	F	−32
462	71....	8.6	0.12	0.09	0.15	0.12	0.67	0.04	0.19	0.48	0.17	0.10	0.07	F	F	F	F	F	−43
679	48....	7.3	0.15	0.66	0.28	0.25	1.46	0.15	0.59	0.79	0.72	1.03	1.83	0.62	0.63	F	−53	−50	−37
Average....		8.2	0.11	0.15	0.17	0.08	0.48	0.04	0.18	0.39	0.32	0.34	0.59	0.40+	0.40+	....	....	....	−21

TABLE III.—*Concluded*

Cement Index Numbers		C_3A, per cent	Lean Mortar Bars, Mix 1:5								Lean Mortar Bars, Mix 1:6								
			Length Changes, per cent														Sonic Changes, per cent		
			Na_2SO_4		$MgSO_4$	Na_2SO_4		$MgSO_4$		Combination	Na_2SO_4	$MgSO_4$	Combination	Na_2SO_4	$MgSO_4$	Combination	$NaSO_4$	$MgSO_4$	Combination
			0.78*M*		0.78*M*	0.15*M*	0.50*M*	0.15*M*	0.50*M*	0.50*M*	0.15*M*	0.15*M*	0.50*M*	0.15*M*	0.15*M*	0.50*M*	0.15*M*	0.15*M*	0.50*M*
			21 days	21 days	21 days	28 days	28 days	28 days	28 days	28 days	28 days	28 days	14 days	28 days	28 days	14 days	28 days	28 days	7 days
			NBS	UF	UF	UF	UF	UF	UF	UF	CPCC	CPCC	CPCC	PCA	PCA	PCA	PCA	PCA	PCA
			(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)
										GROUP 7									
558	92	9.6	0.16	0.14	0.05	0.04	0.38	0.03	0.10	0.31	0.59	0.16	0.83	0.57	0.24	F	−35	5	−24
659	121	10.8	0.20	0.42	0.37	0.14	1.08	0.10	0.37	0.86	0.32	0.09	0.20	F	F	F	F	F	−31
573	95	10.7	0.11	0.09	0.09	0.02	0.23	0.04	0.19	0.24	0.49	0.20	0.64	0.43	0.27	0.74	−24	−5	1
667	124	10.0	0.07	0.33	0.47	0.28	1.28	0.15	0.75	0.88	0.16	0.18	0.20	F	F	F	F	F	−35
682	130	3.9	0.00	0.18	0.22	0.05	0.61	0.05	0.33	0.45	0.04	0.04	0.28	F	F	F	−48	F	−39
453	70	6.8	0.30	0.18	0.50	0.15	0.92	0.08	0.65	0.74	0.06	0.12	0.10	0.48	F	F	−36	F	−25
399	55	9.0	0.06	0.14	0.15	0.12	0.72	0.09	0.34	0.76	0.77	0.58	0.68	0.57	0.17	0.30	−55	3	19
567	94	10.9	0.08	0.17	0.05	0.06	0.62	0.04	0.15	0.27	0.19	0.08	0.67	0.51	0.31	1.02	−33	1	−24
438	67	9.3	0.04	0.07	0.07	0.03	0.17	0.03	0.15	0.23	0.13	0.06	0.11	0.37	0.51	F	−15	−22	−35
545	91	10.9	0.15	0.38	0.29	0.10	0.91	0.10	0.19	0.59	0.19	0.33	0.25	F	0.47	F	F	−25	−32
Average		9.2	0.12	0.21	0.23	0.10	0.69	0.07	0.32	0.53	0.38	0.21	0.40	....	....	....	....	....	−22
										GROUP 8									
599	44	6.4	0.05	0.04	0.05	0.02	0.04	0.02	0.02	0.07	0.17	0.80	0.58	0.18	0.30	0.67	−15	−34	−27
549	41	9.1	0.25	0.20	0.03	0.07	0.82	0.05	0.02	0.08	0.48	0.60	0.45	0.53	0.52	1.09	−48	−35	−38
402	56	8.6	0.09	0.18	0.37	0.16	0.52	0.05	0.34	0.79	0.47	0.68	0.48	F	F	1.17	F	F	−36
653	119	9.6	0.34	0.43	0.64	0.58	1.35	0.21	0.82	1.51	1.09	0.76	0.36	F	F	F	F	F	−44
465	72	10.4	0.14	0.37	0.27	0.08	0.88	0.05	0.34	0.80	0.16	0.23	0.14	F	F	F	F	F	−41
501	81	11.0	0.16	0.36	0.28	0.14	1.03	0.04	0.20	0.35	0.26	0.31	0.06	0.49	0.41	F	−27	−20	−24
492	79	9.8	0.06	0.17	0.05	0.06	0.75	0.04	0.17	0.53	0.19	0.23	0.07	F	F	F	F	F	−17
619	107	9.6	0.20	0.06	0.05	0.03	0.29	0.02	0.12	0.20	0.37	0.58	0.36	0.50	F	F	−25	F	−20
459	14	6.7	0.28	0.20	0.15	0.15	0.94	0.04	0.21	0.36	0.48	0.34	1.52	0.51	0.43	1.30	−47	−23	−38
423	62	8.8	0.20	0.30	0.85	0.51	0.87	0.16	1.09	1.35	0.86	1.01	1.05	F	F	F	F	F	−45
Average		9.0	0.18	0.23	0.28	0.18	0.79	0.07	0.33	0.61	0.45	0.55	0.51	....	....	....	....	....	−33
										GROUP 9									
495	80	9.7	0.16	0.51	1.08	1.10	2.45	0.37	1.78	1.57	0.96	0.31	0.63	F	F	F	F	F	−48
477	75	11.9	0.44	1.32	1.50	1.75	F	0.47	1.93	1.96	1.06	1.35	1.22	F	F	F	F	F	−38
629	45	11.6	0.10	0.52	0.63	0.67	F	0.22	0.29	0.72	F	1.36	0.68	F	0.38	F	F	−20	3
450	36	6.1	0.31	0.62	0.68	0.23	1.38	0.12	0.69	0.79	0.16	0.33	0.37	0.59	F	F	−54	F	−42
552	42	8.4	0.39	0.41	0.12	0.08	0.97	0.09	0.17	0.43	0.43	0.94	0.68	0.55	F	F	−47	F	F
420	34	11.3	0.28	1.50	1.27	1.01	F	0.59	1.17	1.82	F	F	1.51	F	F	F	F	F	−41
663	123	10.0	0.13	0.15	0.36	0.19	0.83	0.15	0.16	0.86	0.09	0.12	0.19	F	F	F	F	F	−33
447	69	8.0	0.30	0.65	0.42	0.23	1.31	0.15	0.23	0.80	0.06	0.07	0.06	F	F	F	F	F	−46
669	126	11.8	0.20	0.39	0.69	0.37	1.71	0.19	0.47	1.09	0.15	0.05	0.11	F	F	0.91	F	−28	−18
615	105	14.1	F	F	0.49	0.39	F	0.12	0.67	1.71	0.94	1.05	0.63	F	F	F	F	F	−35
Average		10.3	0.26	0.67+	0.72	0.60		0.25	0.76	1.18	....	....	0.61	....	....	....	....	....	

GROUP 10																			
620	108....	11.4	0.09	0.20	0.15	0.28	1.03	0.12	0.37	0.96	0.62	0.38	0.31	F	F	F	F	F	−23
618	106....	13.5	0.15	0.54	0.09	0.17	1.72	0.05	0.12	0.60	0.63	0.24	0.28	F	F	F	F	F	−31
627	110....	9.3	0.11	0.24	0.33	0.96	1.54	0.26	1.12	1.76	1.14	0.65	0.88	F	F	F	F	F	−42
456	37....	6.8	0.24	0.60	0.71	0.37	1.75	0.09	0.70	0.90	0.36	0.63	1.00	0.54	F	F	−53	F	−54
504	82....	10.0	0.14	0.16	0.21	0.31	0.48	0.16	0.75	1.12	0.88	0.35	0.56	F	F	F	F	F	−32
645	30....	8.5	0.10	0.37	0.86	0.81	1.65	0.39	0.98	1.42	F	F	1.97	F	F	1.35	F	F	−35
641	113....	10.4	0.18	0.73	0.69	F	F	0.51	0.90	2.43	0.57	0.31	0.39	F	F	F	F	F	−20
656	120....	10.5	0.35	0.59	1.12	1.95	2.08	0.59	1.70	2.37	0.70	0.87	0.57	F	F	F	F	F	−48
602	101....	9.9	0.20	0.33	0.25	F	2.05	0.26	0.95	1.85	0.67	0.14	0.12	F	F	F	F	F	−35
650	118....	11.0	0.46	0.82	1.18	F	1.98	0.57	0.83	2.24	0.77	1.21	0.46	F	F	F	F	F	F
Average....		10.1	0.20	0.46	0.56	....	....	0.30	0.84	1.57	....	....	0.71	....	....	....	....	....	....
GROUP 11																			
594	25....	12.9	0.43	0.30	0.54	0.17	1.36	0.18	0.79	0.87	0.49	0.88	1.01	F	F	1.58	F	F	−18
644	115....	9.5	0.37	0.40	1.05	0.95	1.81	0.48	1.59	1.58	0.88	1.11	1.45	F	F	F	F	F	F
372	49....	12.6	0.22	0.48	1.06	1.30	2.09	0.55	2.17	1.98	F	F	1.98	F	F	F	F	F	−34
579	96....	11.6	0.20	0.51	0.28	1.21	F	0.48	1.40	1.83	0.11	0.09	0.79	F	F	F	F	F	−44
537	88....	10.3	0.43	0.33	0.28	0.45	1.99	0.24	0.78	F	0.26	0.05	0.14	F	F	F	F	F	−30
685	132....	10.2	0.71	0.86	1.06	F	F	0.70	2.29	F	0.70	0.56	1.03						
595	99....	12.6	0.17	0.08	0.01	F	F	0.03	0.74	0.65	0.34	0.26	0.55	F	F	F	F	F	−31
411	59....	11.9	0.25	0.41	1.78	0.52	2.02	0.30	1.64	1.92	0.62	0.53	0.95	F	F	F	F	F	−29
375	50....	10.9	0.24	0.52	0.38	F	F	0.38	1.29	2.04	F	F	2.34	F	F	F	F	F	−39
668	125....	8.5	0.07	0.14	1.18	0.69	0.72	0.36	1.19	1.54	0.34	0.46	1.04	F	F	F	F	F	−34
Average....		11.2	0.30	0.40	0.76	....	....	0.37	1.39	....	....	....	1.07	....	....	....	....	....	....
GROUP 12																			
480	76....	13.4	0.44	1.37	0.97	1.07	F	0.08	0.31	1.24	0.64	0.51	0.07	F	F	1.27	F	F	−21
522	85....	11.6	0.77	0.95	0.89	F	F	0.49	1.89	F	0.70	0.57	0.42	F	F	F	F	F	−43
417	61....	11.0	0.31	0.80	1.98	1.56	F	0.45	1.16	2.40	0.60	0.94	1.12	F	F	F	F	F	−64
632	112....	11.4	0.20	0.31	0.48	1.36	2.34	0.19	0.50	1.38	F	1.14	0.58	F	F	F	F	F	−40
429	64....	13.3	0.47	1.96	2.13	F	F	0.61	1.51	F	0.80	0.43	0.67	F	F	F	F	F	F
595	98....	13.8	1.10	1.98	0.66	F	F	0.24	0.39	1.55	F	F	1.07	F	F	F	F	F	−13
468	73....	12.0	1.10	0.48	0.58	F	F	0.66	2.08	F	1.22	1.24	0.43	F	F	F	F	F	−53
680	128....	13.5	0.24	0.48	2.13	F	F	0.78	F	F	0.29	0.28	1.12	F	F	F	F	F	−31
630	111....	10.8	0.40	1.07	1.08	2.37	F	0.33	1.12	2.39	F	0.76	1.20	F	F	F	F	F	−34
662	122....	14.2	0.70	1.84	F	F	F	2.58	F	F	F	0.55	0.52	F	F	F	F	F	−47
483	77....	11.7	0.70			1.94	2.39	0.51	1.78	2.69	0.29	0.19	0.04	F	F	F	F	F	−27
Average....		12.4	0.64	1.12	1.10+	....	....	0.69	....	....	....	....	0.72	....	....	....	....	....	....

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[a] Value is for C_2F and is not included in average for C_3A.

[b] F indicates disintegration or that deterioration has progressed beyond the capacity of the measuring equipment.

TABLE IV.—MISCELLANEOUS SHORT-TIME TESTS MADE OF THE 121 CEMENTS OF TABLE I BY FOUR LABORATORIES IN STUDIES OF ACCEPTANCE TESTS FOR SULFATE RESISTANCE.

Columns are lettered at the top to facilitate comparison with data of Table V.

Cement Index Numbers		C_3A, per cent	Autoclave Expansion, per cent	Water Floc Test, per cent			Merriman Sugar Test		Merriman Slab Test				Standard Briquets Rated Visually After 6 months in 5 per cent Solutions	
				Paul's Method			ml. of 0.5 N HCl		28 days	Days to Fail	28 days	Days to Fail	Na_2SO_4	$MgSO_4$
			PRA	PRA	NRC	UF	BWS	NRC	BWS	BWS	NRC	NRC	UF	UF
			(R)	(S)	(T)	(U)	(V)	(W)	(X)		(Y)		(Z)	(AA)
GROUP 1														
611	103....	5.4	0.00	0.00	0.45	0.50	2.7	2.7	O.K.	......	O.K.	......	7	7
631	29....	3.3	−0.05	0.00	0.40	0.78	2.4	2.4	O.K.	......	O.K.	......	7	7
531	19....	3.5	0.00	0.00	0.35	0.63	2.1	2.1	O.K.	......	O.K.	......	8	7
405	57....	5.1	−0.01	0.00	0.30	0.62	5.8	4.3	O.K.	......	O.K.	......	8	8
591	24....	3.9	0.05	0.47	0.50	0.68	12.8	5.1	O.K.	......	O.K.	......	7	7
576	22....	3.7	0.04	0.00	0.35	0.20	25.8	4.3	O.K.	......	O.K.	......	8	6
426	63....	4.1	0.03	0.00	0.35	0.51	3.8	3.8	O.K.	......	O.K.	......	7	6
647	117....	5.2	0.01	0.00	0.40	0.49	2.3	2.4	O.K.	......	O.K.	......	......	......
628	28....	1.4[a]	−0.01	0.00	0.25	0.51	8.9	7.2	O.K.	......	O.K.	......	7	7
582	23....	5.2	0.04	0.37	0.30	0.47	38.2	10.6	O.K.	......	O.K.	......	5	6
Average....		4.4	0.01	0.08	0.37	0.54	10.5	4.5	......	......	......	......	7.1	6.8
GROUP 2														
596	100....	6.7	0.08	1.67	1.75	1.77	42.0	36.2	O.K.	......	O.K.	......	5	7
387	53....	5.6	0.02	0.62	0.75	0.63	8.1	6.4	O.K.	......	O.K.	......	4	5
621	27....	2.5	0.14	0.00	0.25	0.19	2.0	2.2	O.K.	......	O.K.	......	8	7
390	54....	5.3	0.14	0.62	0.45	0.62	38.8	31.6	O.K.	......	O.K.	......	6	6
507	17....	2.2	0.08	0.00	0.35	0.20	5.5	3.5	O.K.	......	O.K.	......	7	6
605	26....	2.9	0.09	0.00	0.30	0.27	2.2	2.3	O.K.	......	O.K.	......	8	8
561	93....	6.2	0.02	0.00	0.70	0.46	6.1	4.4	O.K.	......	O.K.	......	8	8
393	33....	4.3	0.09	0.00	0.35	0.46	5.3	4.7	O.K.	......	O.K.	......	6	7
489	16....	4.9	0.01	0.00	0.45	0.28	2.4	2.6	O.K.	......	O.K.	......	6	7
543	20....	4.0	0.05	0.00	0.95	0.36	37.1	9.1	O.K.	......	O.K.	......	5	7
Average....		4.5	0.07	0.29	0.63	0.52	15.0	10.3	......	......	......	......	6.3	6.8
GROUP 3														
516	84....	9.7	0.07	0.70	1.05	1.40	5.3	3.7	O.K.	......	G[b]	56	2	4
381	12....	4.2	0.10	0.00	0.35	0.37	1.9	2.4	O.K.	......	O.K.	......	6	6
608	102....	5.6	0.02	0.00	0.45	0.47	2.7	2.5	O.K.	......	O.K.	......	6	7
513	18....	0.7	0.49	0.00	0.30	0.40	2.7	2.8	O.K.	125	O.K.	......	6	6
441	68....	7.1	0.03	0.35	0.45	0.73	10.4	8.3	O.K.	......	O.K.	......	6	7
681	129....	5.2	−0.02	0.75	0.60	0.62	47.7	34.5	O.K.	......	O.K.	......	......	......
665	32....	5.8	0.03	0.00	0.40	0.46	2.3	2.5	O.K.	......	O.K.	......	......	......
646	116....	5.4	0.02	0.00	0.55	0.47	3.1	3.0	O.K.	......	O.K.	......	......	......
683	131....	5.0	0.02	0.72	1.00	1.14	60.6	53.7	O.K.	......	O.K.	......	......	......
643	114....	6.6	0.12	0.96	1.90	1.17	20.8	8.7	O.K.	......	O.K.	......	......	......
Average....		5.5	0.09	0.35	0.71	0.72	15.8	12.2	......	......	......	......	5.2	6.0
GROUP 4														
534	40....	6.7	−0.01	0.00	0.55	0.47	44.1	25.7	O.K.	......	O.K.	......	3	5
396	13....	5.4	0.05	0.00	0.25	0.20	2.1	2.3	O.K.	......	O.K.	......	4	6
519	39....	7.5	0.03	1.25	2.30	1.87	61.8	24.7	O.K.	......	O.K.	......	2	5
540	89....	7.2	0.09	1.53	1.70	1.12	51.1	45.0	O.K.	......	O.K.	......	4	5
528	87....	6.7	0.05	1.32	1.25	1.02	51.7	45.6	O.K.	......	O.K.	......	6	7
378	51....	8.7	0.40	1.25	2.70	2.51	52.7	50.9	O.K.	110	O.K.	......	6	7
664	31....	6.0	0.06	0.00	0.50	0.71	3.2	3.3	O.K.	......	O.K.	......	......	......
432	65....	7.4	0.07	1.08	1.80	2.27	48.6	46.9	O.K.	......	O.K.	......	4	7
486	78....	9.0	0.04	0.00	0.35	0.71	3.8	3.7	O.K.	......	O.K.	......	5	7
570	43....	10.3	0.01	1.31	1.50	1.14	3.8	4.0	O.K.	44	O.K.	......	4	7
Average....		7.5	0.08	0.77	1.29	1.20	32.3	25.2	......	......	......	......	4.2	6.2

TABLE IV.—*Continued*

Cement Index Numbers		C$_3$A, per cent	Auto-clave Expansion, per cent	Water Floc Test, per cent			Merriman Sugar Test		Merriman Slab Test				Standard Briquets Rated Visually After 6 months in 5 per cent Solutions	
				Paul's Method			ml. of 0.5 *N* HCl		28 days	Days to Fail	28 days	Days to Fail	Na$_2$SO$_4$	MgSO$_4$
			PRA	PRA	NRC	UF	BWS	NRC	BWS	BWS	NRC	NRC	UF	UF
			(R)	(S)	(T)	(U)	(V)	(W)	(X)		(Y)		(Z)	(AA)
GROUP 5														
444	35	7.3	0.04	0.69	3.50	1.48	60.0	58.3	O.K.	...	O.K.	...	6	6
666	47	5.3	0.01	1.07	1.70	1.19	62.5	66.9	O.K.	58	O.K.	...	...	...
435	66	9.5	0.05	0.97	2.25	2.56	47.7	48.9	O.K.	...	O.K.	...	4	6
525	86	9.7	0.09	0.16	2.10	2.67	56.4	52.7	O.K.	...	O.K.	...	3	5
414	60	9.6	0.01	1.11	1.70	0.99	43.8	11.8	O.K.	...	O.K.	...	1	5
614	104	8.9	−0.01	2.06	2.10	2.25	40.7	40.3	O.K.	...	O.K.	...	3	5
474	74	9.6	0.03	1.07	2.15	1.57	8.9	6.7	O.K.	89	G	56	4	6
471	15	4.8	0.12	0.00	0.30	0.65	27.3	3.4	O.K.	...	O.K.	...	5	6
642	46	10.3	0.18	5.17	8.20	9.60	54.8	55.8	O.K.	51	G	49	...	
670	127	6.7	0.18	1.83	2.40	2.77	53.4	46.5	O.K.	...	O.K.	...	...	...
Average		8.2	0.07	1.41	2.64	2.57	45.6	39.1	...	...	...	...	3.7	5.6
GROUP 6														
590	97	9.7	0.08	0.44	0.70	1.26	6.3	4.5	O.K.	...	F^c	27	4	7
564	21	6.0	0.00	0.00	0.25	0.30	2.1	2.3	O.K.	...	O.K.	...	6	6
498	38	9.1	0.04	1.71	2.80	3.51	60.9	52.4	O.K.	59	G	63	1	5
624	109	8.4	0.23	0.84	1.85	1.09	51.6	40.8	O.K.	...	O.K.	...	7	6
403	58	6.0	0.00	0.00	0.40	0.14	3.9	3.5	O.K.	...	O.K.	...	7	7
384	52	9.7	0.22	0.31	1.05	1.16	6.4	4.9	O.K.	...	O.K.	...	4	6
546	90	9.0	0.06	1.26	1.70	1.49	50.3	42.0	O.K.	...	O.K.	...	2	5
510	83	8.6	0.37	0.66	1.20	1.31	4.1	3.5	O.K.	...	F	23	1	4
462	71	8.6	0.16	1.59	2.10	1.27	9.8	10.8	O.K.	...	G	56	2	5
679	48	7.3	0.06	1.45	2.30	2.32	52.6	56.1	O.K.	58	O.K.	...	...	...
Average		8.2	0.12	0.83	1.44	1.39	24.8	22.1	...	...	...	...	3.8	5.7
GROUP 7														
558	92	9.6	0.06	1.59	1.45	1.10	46.3	16.2	O.K.	...	G	70	2	6
659	121	10.8	0.01	2.02	1.90	1.21	54.7	47.4	O.K.	...	O.K.	...	...	...
573	95	10.7	0.13	2.60	2.90	3.00	43.2	30.3	O.K.	...	O.K.	...	3	7
667	124	10.0	0.06	2.62	2.50	1.37	58.3	53.0	O.K.	88	G	28	...	...
682	130	3.9	0.33	0.75	0.85	0.41	67.7	55.6	O.K.	...	O.K.	...	...	...
453	70	6.8	0.11	1.99	3.50	2.20	60.1	59.4	O.K.	...	O.K.	...	2	4
399	55	9.0	0.48	0.92	1.30	1.00	3.8	3.2	O.K.	95	G	56	2	4
567	94	10.9	0.09	2.53	1.70	1.24	4.2	3.4	O.K.	...	G	56	3	5
438	67	9.3	0.04	0.00	0.45	0.29	4.4	3.8	O.K.	...	O.K.	...	1	5
555	91	10.9	0.15	2.92	2.60	1.63	8.2	4.6	O.K.	...	G	49	2	6
Average		9.2	0.15	1.73	1.92	1.35	35.1	27.7	...	...	...	...	2.1	5.3
GROUP 8														
599	44	6.4	0.15	0.00	0.30	0.39	46.0	52.7	O.K.	...	O.K.	...	4	6
549	41	9.1	0.02	2.06	2.30	2.36	76.7	74.0	O.K.	44	O.K.	...	0	5
402	56	8.6	0.31	0.99	1.20	0.94	4.5	3.8	O.K.	...	G	46	0	5
653	119	9.6	0.12	2.37	2.35	2.26	61.2	53.5	O.K.	95	G	35	...	...
465	72	10.4	0.06	2.13	2.40	1.30	47.4	46.6	O.K.	89	G	46	2	5
501	81	11.0	0.14	6.29	4.40	6.44	65.5	58.6	O.K.	81	G	42	2	5
492	79	9.8	0.09	3.32	2.80	2.15	34.2	9.5	O.K.	60	G	28	2	5
619	107	9.6	0.26	1.59	1.80	1.48	3.2	3.0	O.K.	...	O.K.	...	2	5
459	14	6.7	0.11	1.65	2.80	4.74	72.2	64.2	O.K.	87	O.K.	...	1	5
423	62	8.8	0.92	1.14	2.85	1.25	39.5	32.7	O.K.	...	F	23	0	3
Average		9.0	0.22	2.15	2.32	2.33	45.0	39.9	...	...	...	...	1.4	4.9

TABLE IV.—*Concluded*

Cement Index Numbers	C_3A, per cent	Auto-clave Expansion, per cent	Water Floc Test, per cent			Merriman Sugar Test		Merriman Slab Test				Standard Briquets Rated Visually After 6 months in 5 per cent Solutions	
			Paul's Method			ml. of 0.5 *N* HCl		28 days	Days to Fail	28 days	Days to Fail	Na_2SO_4	$MgSO_4$
		PRA	PRA	NRC	UF	BWS	NRC	BWS	BWS	NRC	NRC	UF	UF
		(R)	(S)	(T)	(U)	(V)	(W)	(X)		(Y)		(Z)	(AA)
GROUP 9													
495 80	9.7	0.15	2.74	2.95	3.90	58.9	40.4	O.K.	53	G	42	2	5
477 75	11.9	0.09	2.33	3.00	3.96	63.9	59.6	O.K.	74	O.K.	35	0	1
629 45	11.6	0.36	5.71	10.10	15.10	67.4	70.3	O.K.	37	G	49	1	6
450 36	6.1	0.07	1.21	2.30	3.63	60.2	48.0	O.K.	......	O.K.	......	4	5
552 42	8.4	0.10	1.48	3.10	4.52	71.9	69.4	O.K.	......	O.K.	......	2	6
420 34	11.3	0.12	2.27	4.40	8.92	55.2	41.0	O.K.	52	G	35	0	3
663 123	10.0	0.12	1.19	0.80	1.45	49.4	29.8	O.K.	......	O.K.	......	......	......
447 69	8.0	0.13	2.05	2.15	2.39	57.5	62.2	O.K.	89	G	56	0	5
669 126	11.8	0.12	2.39	2.10	2.42	7.6	5.3	O.K.	51	G	35	......	......
615 105	14.1	0.07	2.81	2.60	2.80	50.3	48.2	F	13	F	11	0	5
Average	10.3	0.13	2.42	3.35	4.91	54.2	47.4	......	......	......	......	1.1	4.5
GROUP 10													
620 108	11.4	0.25	0.73	0.90	1.16	2.8	2.8	O.K.	......	G	35	1	5
618 106	13.5	0.12	2.43	1.30	1.52	8.3	4.3	O.K.	42	G	35	2	5
627 110	9.3	0.18	13.50	7.55	7.99	58.2	53.3	O.K.	53	F	18	2	5
456 37	6.8	0.10	1.97	3.40	4.57	72.2	69.0	O.K.	59	O.K.	......	1	2
504 82	10.0	0.27	2.13	2.35	1.59	46.7	36.1	O.K.	110	O.K.	35	0	2
645 30	8.5	0.14	1.29	2.50	2.37	57.0	56.6	O.K.	52	G	35	......	......
641 113	10.4	0.33	3.75	7.80	6.25	4.4	4.0	F	14	F	17	......	......
656 120	10.5	0.38	1.69	2.95	3.52	56.9	45.5	F	28	F	27	......	......
602 101	9.9	0.65	3.00	3.50	3.90	18.2	5.3	O.K.	45	F	19	0	4
650 118	11.0	0.22	4.42	3.70	4.30	61.0	51.6	O.K.	38	F	19	......	......
Average	10.1	0.26	3.49	3.60	3.72	38.6	32.9	......	......	......	......	1.0	3.8
GROUP 11													
594 25	12.9	0.15	18.75	4.50	25.14	48.3	40.2	O.K.	59	G	35	1	3
644 115	9.5	0.18	1.45	2.50	3.81	54.9	46.1	O.K.	32	F	19	......	......
372 49	12.6	0.20	2.75	4.90	5.78	55.9	52.3	F	21	F	19	0	3
579 96	11.6	0.13	3.86	4.40	2.19	52.6	45.2	O.K.	38	F	19	0	2
537 88	10.3	0.20	3.03	2.90	2.55	39.6	8.2	O.K.	109	F	21	0	2
685 132	10.2	0.35	9.39	6.55	8.40	54.5	47.1	F	10	F	14	......	......
595 99	12.6	0.40	......	4.70	2.15	26.8	38.6	F	13	F	20	1	3
411 59	11.9	0.03	0.41	1.05	1.09	28.2	6.2	O.K.	89	F	26	0	1
375 50	10.9	0.55	5.67	5.20	4.04	53.9	55.4	F	15	F	19	0	3
668 125	9.5	0.34	6.49	3.90	3.94	54.4	45.3	F	28	F	23	......	......
Average	11.2	0.25	5.80	4.06	5.91	46.9	38.5	......	......	......	......	0.3	2.4
GROUP 12													
480 76	13.4	0.29	6.68	7.45	13.05	65.8	54.6	F	24	F	17	0	3
522 85	11.6	0.20	6.98	10.10	9.14	67.6	62.3	F	19	F	14	0	3
417 61	11.0	0.20	2.55	3.35	4.34	52.3	51.7	O.K.	32	F	19	0	0
632 112	11.4	0.17	5.76	3.90	5.35	56.5	47.9	F	28	F	28	0	3
429 64	13.3	0.22	4.72	6.45	10.12	59.6	34.1	F	24	F	24	0	2
593 98	13.8	0.22	15.18	12.30	14.11	61.6	55.0	F	14	F	10	1	4
468 73	12.0	1.55	4.81	4.80	6.59	57.2	52.0	F	13	F	17	0	3
680 128	13.5	0.49	6.94	4.30	4.32	64.7	50.2	F	12	F	16	......	......
630 111	10.8	0.39	3.83	4.60	4.74	58.8	48.5	O.K.	39	F	16	0	2
662 122	14.2	0.82	15.37	9.75	11.67	73.2	67.6	F	28	F	15	......	......
483 77	11.7	0.94	7.82	4.85	6.85	47.1	39.7	F	13	F	14	0	2
Average	12.4	0.50	7.33	6.53	8.21	60.4	51.2	......	......	......	......	0.1	2.4

[a] Value is for C_2F and is not included in average for C_3A.
[b] G indicates gradual disintegration.
[c] F indicates failure.

TABLE V.—NUMBER OF CEMENTS IN EACH OF THE TWELVE GROUPS OF TABLE I WHICH WOULD MEET SPECIFICATION LIMITS AS SHOWN FOR THE VARIOUS TESTS MADE AT THE SEVERAL LABORATORIES AND SUMMARIZED IN TABLES III AND IV.

Columns are lettered at the top to facilitate comparison with data of Tables III and IV.

Cements as Grouped in Table I by Long-Time Tests at University Farm	C_3A				Water Floc Test							Lean Mortar Bars (Mix 1:5 or 1:6 as Indicated)																	
	Chemical Analyses by NBS, Compounds Calculated at UF			Autoclave Expansion	Paul's Method			Merriman Sugar Solubility Test		Merriman Slab Test		0.15 *M* Na_2SO_4				0.15 *M* $MgSO_4$				Combination 0.50 *M* (0.25 *M* Na_2SO_4 and 0.25 *M* $MgSO_4$)				0.50 *M* Na_2SO_4	0.50 *M* $MgSO_4$	0.78 *M* Na_2SO_4		0.78 *M* $MgSO_4$
												Days Exposure				Days Exposure				Days Exposure				Days Exposure		Days Exposure		
												28	28	28	28	28	28	28	28	28	14	14	7	28	28	21	21	21
												1:5	1:6	1:6	1:6	1:5	1:6	1:6	1:6	1:5	1:6	1:6	1:6	1:5	1:5	1:5	1:5	1:5
				PRA	PRA	NRC	UF	BWS	NRC	BWS	NRC	UF	CCPC	PCA	PCA	UF	CCPC	PCA	PCA	UF	CCPC	PCA	PCA	UF	UF	NBS	UF	UF
	Per cent Limit				Per cent Limit			ml. of 0.5 *N* HCl		Days to fail		Expansion Limit, per cent			Sonic	Expansion Limit, per cent			Sonic	Expansion Limit, per cent			Sonic	Expansion Limit, per cent				
	5	6	7	0.05	0.80	0.80	0.80	10	10	90	90	0.02	0.10	0.20	−20%	0.02	0.25	0.35	−20%	0.25	0.40	0.90	−20%	0.10	0.15	0.06	0.06	0.10
				(R)	(S)	(T)	(U)	(V)	(W)	(X)	(Y)	(D)	(I)	(L)	(O)	(F)	(J)	(M)	(P)	(H)	(K)	(N)	(Q)	(E)	(G)	(A)	(B)	(C)
I	6	10	10	10	10	10	10	7	9	10	10	10	10	10	10	10	5	9	10	10	4	8	9	10	8	10	10	7
II	6	8	10	4	9	8	9	7	8	10	10	9	9	9	9	10	5	7	7	9	3	7	9	9	10	9	10	9
III	3	7	8	6	9	7	7	6	8	10	9	8	7	5	7	8	7	4	8	8	6	4	4	6	6	8	8	8
IV	0	2	4	6	4	4	4	4	4	9	10	5	5	7	7	3	5	6	6	8	6	7	6	4	8	5	4	6
V	1	2	3	6	3	1	1	1	2	7	8	3	3	0	1	4	4	2	1	5	5	2	0	1	5	1	3	4
VI	0	2	2	3	5	3	2	6	5	8	6	2	3	3	3	2	3	4	4	4	4	4	5	1	7	3	3	4
VII	1	1	2	2	2	1	2	4	4	9	5	1	2	0	1	0	8	4	4	2	6	2	2	0	3	3	0	4
VIII	0	0	2	1	1	1	1	2	3	5	4	1	0	1	1	2	2	1	1	3	5	1	2	1	3	2	2	4
IX	0	0	1	0	0	0	0	1	1	3	3	0	2	0	0	0	3	0	1	0	4	0	2	0	0	0	0	0
X	0	0	1	0	1	0	0	3	4	2	1	0	0	0	0	0	2	0	0	0	4	0	1	0	1	0	0	1
XI	0	0	0	1	1	0	0	0	2	1	0	0	0	0	0	0	2	0	0	0	1	0	1	0	0	0	0	1
XII	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	1	0	0	0	0	0
Totals	17	32	43	39	45	35	36	41	50	74	66	39	41	35	39	39	47	37	42	49	50	35	42	32	51	41	40	48

TABLE VI.—LENGTH INCREASES IN PER CENT OF 1:5 OTTAWA STANDARD SAND BARS MADE OF 3 LOTS OF 10 CEMENTS, 1 BY 1 BY 6¼-IN. BARS WITH 5-IN. NET LENGTHS.
Data from Cooperative Drain Tile Laboratory, University Farm.

Cements Stored 5 yr. in Air-Tight Cans and Tested During 1941 and 1942						Fresh Lots of Cements Tested During Spring of 1943				Fresh Lots of Cements Tested During Winter of 1943 and 1944						
Cement Number	Run					Cement Number	Run			Cement Number	Run					
	1	2	3	4	Avg.		1	2	Avg.		1	2	3	4	5	Avg.
							DISTILLED WATER									
405	0.01	......	......	0.01	0.01	769	0.01	0.01	−0.01	779	0.00	−0.01	0.00	0.00	0.00	0.00
426	0.02	......	......	0.00	0.01	778	0.00	0.01	0.00	780	−0.01	0.00	0.00	0.00	0.00	0.00
390	0.01	0.01	......	0.00	0.01	770	0.00	0.02	0.01	781	0.00	0.00	0.00	0.00	0.00	0.00
441	0.00	......	......	0.01	0.00	771	0.00	0.01	0.00	782	0.00	−0.01	0.00	0.00	0.01	0.00
486	0.02	0.00	......	0.01	0.01	773	0.01	0.01	0.01	785	0.00	−0.01	0.00	0.00	0.00	0.00
614	0.01	0.00	......	0.01	0.01	......	......	......	......	783	−0.01	−0.01	0.00	0.00	0.00	0.00
384	−0.01	0.00	......	0.01	0.00	772	0.01	0.01	0.01	784	0.01	−0.01	0.00	0.01	0.01	0.00
411	0.01	0.01	......	0.00	0.01	776	0.01	0.02	0.01	786	0.00	0.00	0.00	0.01	0.01	0.00
417	0.00	0.01	......	0.01	0.01	777	0.00	0.01	0.00	787	0.00	0.00	0.00	0.00	0.00	0.00
483	0.00	0.00	......	0.00	0.00	......	......	......	......	788	0.00	−0.01	0.00	0.00	0.01	0.00
							0.15 *M* Na_2SO_4									
405	0.01	0.01	0.00	0.01	0.01	769	0.02	0.02	0.02	779	0.00	0.00	0.01	0.02	0.01	0.01
426	0.04	0.02	0.02	0.01	0.02	778	0.02	0.04	0.03	780	0.01	0.01	0.01	0.01	0.02	0.01
390	0.02	......	0.02	0.02	0.02	770	0.02	0.04	0.03	781	0.01	0.01	0.02	0.01	0.03	0.02
441	0.01	0.01	0.00	0.02	0.01	771	0.01	0.02	0.01	782	0.03	0.06	0.04	0.03	......	0.04
486	0.03	0.01	0.01	0.02	0.02	773	0.07	0.19	0.13	785	0.08	0.08	0.11	0.09	......	0.09
614	0.16	0.10	0.07	0.03	0.09	......	......	......	......	783	0.13	0.44	0.29	0.35	......	0.30
384	0.02	0.04	0.02	0.03	0.03	772	0.06	0.05	0.05	784	0.09	0.13	0.09	0.20	0.09	0.12
411	0.73	0.57	......	0.28	0.53	776	3.31	1.50	2.40	786	0.15	0.35	0.20	0.42	0.50	0.32
417	1.89	1.40	......	1.38	1.56	777	0.81	1.08	0.94	787	0.34	1.23	0.44	0.85	0.92	0.76
483	2.56	1.32	......	......	1.94	......	......	......	......	788	0.02	0.03	0.03	0.02	0.05	0.03
							0.15 *M* $MgSO_4$									
405	0.01	0.00	0.00	0.02	0.01	769	0.02	0.02	0.02	779	0.01	0.01	0.01	0.02	0.01	0.01
426	0.03	0.01	0.01	0.02	0.02	778	0.02	0.04	0.03	780	0.01	0.01	0.02	0.01	0.01	0.01
390	0.03	0.03	0.02	0.02	0.02	770	0.02	0.02	0.02	781	0.02	0.02	0.02	0.02	0.02	0.02
441	0.01	0.01	0.01	0.02	0.01	771	0.02	0.02	0.02	782	0.04	0.04	0.09	0.05	0.10	0.06
486	0.02	0.02	0.00	0.01	0.01	773	0.04	0.11	0.07	785	0.13	0.10	0.16	0.16	0.20	0.15
614	0.06	0.09	0.03	0.04	0.05	......	......	......	......	783	0.13	0.29	0.30	0.24	0.39	0.27
334	0.01	0.02	0.02	0.06	0.03	772	0.04	0.05	0.04	784	0.06	0.05	0.10	0.08	0.08	0.07
411	0.40	0.29	......	0.22	0.30	776	0.30	0.69	0.49	786	0.14	0.25	0.18	0.27	0.27	0.22
417	0.53	0.26	......	0.56	0.45	777	0.33	0.50	0.41	787	0.50	0.48	0.54	0.54	0.56	0.52
483	0.42	0.59	......	......	0.50	......	......	......	......	788	0.02	0.04	0.09	0.03	0.07	0.05

TABLE VII.—LENGTH INCREASES IN PER CENT OF 1:5 OTTAWA STANDARD SAND 1 BY 1-IN. BARS, MADE OF 10 CEMENTS AND EXPOSED FOR 28 DAYS AS INDICATED.

NOTE.—The results reported are of 5-in. bars made at 4 laboratories and 10-in. bars at 2 laboratories. Each result is the average of 3 to 6 bars made on 3 or more days.

Cement Number	C_3A	Water Stored					0.15 *M* Na_2SO_4					0.15 *M* $MgSO_4$				
		Laboratory Designation					Laboratory Designation					Laboratory Designation				
		UF	CPCC	PCA	CHD	Avg.	UF	CPCC	PCA	CHD	Avg.	UF	CPCC	PCA	CHD	Avg.
6¼-IN. BARS WITH 5-IN. NET LENGTHS																
780	6.3	0.00	0.01	0.00	......	......	0.01	0.02	0.02	0.02	0.02	0.01	0.03	0.01	0.03	0.02
779	6.5	0.00	0.00	0.00	......	......	0.01	0.06	0.02	0.02	0.03	0.01	0.02	0.01	0.04	0.02
781	6.6	0.00	0.01	0.01	......	......	0.02	0.06	0.02	0.02	0.03	0.02	0.06	0.02	0.03	0.03
782	8.1	0.00	0.00	0.00	......	......	0.04	0.26	0.04	0.03	0.09	0.06	0.13	0.02	0.05	0.06
785	9.4	0.00	0.00	0.00	......	......	0.09	0.18	0.07	0.02	0.09	0.15	0.16	0.03	0.04	0.09
784	9.5	0.00	0.01	0.01	......	......	0.12	0.13	0.08	0.05	0.10	0.07	0.08	0.03	0.04	0.05
783	10.3	0.00	0.00	0.00	......	......	0.30	0.44	0.15	0.08	0.24	0.27	0.30	0.02	0.10	0.17
786	11.0	0.00	0.01	0.01	......	......	0.32	0.45	0.06	0.11	0.23	0.22	0.41	0.03	0.15	0.20
788	11.2	0.00	0.01	0.00	......	......	0.03	0.63	0.04	0.02	0.18	0.05	0.39	0.03	0.04	0.13
787	12.1	0.00	0.01	0.00	......	......	0.76	0.62	0.14	0.12	0.41	0.52	0.18	0.07	0.09	0.21
Average		0.00	0.01	0.00	......	......	0.17	0.29	0.06	0.05	0.14	0.14	0.18	0.03	0.06	0.10
11¼-IN. BARS WITH 10-IN. NET LENGTHS																
780	6.3	......	......	0.00	0.00	0.00	......	......	0.01	0.05	0.03	......	......	0.01	0.18	0.10
779	6.5	......	......	0.00	0.00	0.00	......	......	0.01	0.04	0.02	......	......	0.01	0.10	0.06
781	6.6	......	......	0.00	0.01	0.01	......	......	0.02	0.02	0.02	......	......	0.02	0.08	0.05
782	8.1	......	......	0.00	0.01	0.01	......	......	0.02	0.04	0.03	......	......	0.02	0.13	0.08
785	9.4	......	......	0.00	0.00	0.00	......	......	0.02	0.07	0.05	......	......	0.02	0.12	0.07
784	9.5	......	......	0.00	0.01	0.01	......	......	0.06	0.09	0.08	......	......	0.03	0.18	0.11
783	10.3	......	......	0.00	0.01	0.01	......	......	0.06	0.17	0.12	......	......	0.02	0.24	0.13
786	11.0	......	......	0.00	0.01	0.01	......	......	0.07	0.14	0.11	......	......	0.03	0.33	0.18
788	11.2	......	......	0.00	0.01	0.01	......	......	0.04	0.13	0.09	......	......	0.02	0.15	0.09
787	12.1	......	......	0.00	0.01	0.01	......	......	0.09	0.26	0.18	......	......	0.04	0.33	0.19
Average		......	......	0.00	0.01	0.01	......	......	0.04	0.10	0.07	......	......	0.02	0.18	0.11

TABLE VIII.—CHEMICAL ANALYSES OF CEMENTS—SERIES 322.

Data from Research Laboratory of the Portland Cement Association.

Reference Number	Oxide Analysis, per cent												Loss on Ignition, per cent	Insoluble Residue, per cent
	SiO_2[a]	Al_2O_3[b]	Fe_2O_3[c]	CaO[d]	MgO[e]	SO_3	Na_2O	K_2O	FeO	TiO_2	P_2O_5	Mn_2O_3		
1	22.08	4.60	3.38	64.76	1.44	1.51	0.16	0.37	nil.	0.19	0.16	0.13	0.72	0.14
2	22.24	4.06	2.66	63.80	2.59	1.83	0.16	0.38	nil.	0.22	0.15	0.47	1.22	0.15
3	22.16	4.27	2.77	61.17	3.25	1.81	0.18	0.49	0.31	0.16	0.14	0.13	1.39	0.22
4	20.89	4.98	3.00	63.33	1.87	1.91	0.20	0.41	nil.	0.22	0.13	0.10	1.63	0.15
5	23.36	4.17	0.41	63.77	1.32	1.77	0.01	0.14	trace	0.20	0.04	trace	2.64	0.14
6	21.90	5.10	2.37	62.52	3.35	1.30	0.08	0.62	0.08	0.21	0.07	0.14	1.14	0.09
7	21.14	5.36	2.81	63.05	2.02	1.55	0.15	0.81	0.06	0.23	0.10	0.06	1.51	0.10
8	20.34	5.95	2.86	62.38	2.46	1.59	0.13	0.21	0.21	0.24	0.04	0.60	1.13	0.19
9	21.09	5.94	2.18	63.26	2.94	1.78	0.05	0.73	trace	0.24	0.05	0.05	1.06	0.15
10	22.65	5.68	2.28	61.11	2.45	1.91	0.14	0.96	0.03	0.25	0.10	0.08	1.36	0.14

[a] Corrected for insoluble residue.
[b] Corrected for $TiO_2 + P_2O_5$.
[c] Corrected for FeO as Fe_2O_3.
[d] Corrected for free CaO.
[e] Corrected for Mn_2O_3.

TABLE IX.—CALCULATED COMPOSITION AND MISCELLANEOUS TESTS OF CEMENTS—SERIES 322.

Data from Research Laboratory of the Portland Cement Association.

Reference Number	Lot Number	Cement Number (Miller)	Calculated Composition from Corrected Oxides, per cent					Free CaO, per cent	$CHCl_3$ Solution, per cent	Passing No. 325 Sieve, per cent	Specific Surface (Wagner), sq. cm. per g.
			C_3S	C_2S	C_3A	C_4AF	$CaSO_4$				
1	16950	779	55.8	21.2	6.5	10.3	2.6	nil.	nil.	86.2	1620
2	16951	780	54.2	22.9	6.3	8.1	3.1	0.08	0.006	95.4	1890
3	16952	781	42.8	31.3	6.6	8.4	3.1	1.40	trace	91.5	1840
4	16953	782	55.8	17.9	8.1	9.1	3.2	1.15	trace	89.4	1800
5	16954	783	48.3	30.5	10.3	1.3	3.0	2.15	0.008	95.9	2290
6	16955	784	46.8	27.6	9.5	7.2	2.2	0.96	0.006	92.9	1830
7	16956	785	51.4	21.8	9.4	8.6	2.6	0.78	0.003	92.0	1750
8	16957	786	50.7	20.2	11.0	8.7	2.7	0.74	0.015	92.9	1970
9	16958	787	49.0	23.7	12.1	6.6	3.0	0.16	0.005	94.8	1730
10	16959	788	29.7	42.7	11.2	6.9	3.2	0.68	0.014	91.3	1650

APPENDIX

LEAN MORTAR BAR TESTS

Following are the essential details of the lean mortar bar short-time test for which data are recorded in Table III. In a few instances comments have been inserted regarding routine that it is believed would make for improvement in the light of experiences with the test.

Change of Length Method.[9]—Bars shall be 1 by 1 in. with a 5-in. effective gage length, made of Ottawa standard sand (20–30). The mix shall be 1:5 by weight, and the water-cement ratio as calculated from the normal consistency of the cement by the equation following Table II of A.S.T.M. Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 - 44).[6]

This equation is:

$$y = 2/3 \frac{P}{n+1} = K$$

where:

y = percentage of water required for the sand mortar,

P = percentage of water required for neat cement paste of normal consistency,

n = number of parts of sand to one of cement by weight, and

K = a constant which for the standard 20–30 sand has the value 6.5.

Each batch of 6 bars shall consist of 1200 g. of sand, 240 g. of cement, and the calculated amount of water. For a cement of 25.0 per cent normal consistency the calculated quantity of mixing water will be 133.6 ml. (9.28 per cent of the weight of the cement).

The molds shall be thinly coated with petroleum jelly, assembled, and stainless steel reference plugs (¼ by 13/16 in.) shall be screwed into place in the removable 1 by 1-in. end plates, care being taken to keep the plugs clean and free of oil. A 1 by 1-in. piece of cardboard with a hole ¼ in. in diameter at the center shall then be placed at each end of a mold. Any glazed cardboard about 1/64 in. in thickness, oil soaked and allowed to drain overnight, is satisfactory. A layer of neat cement, of fairly stiff consistency, ¼ in. in thickness shall then be pressed against the oiled cardboard at each end of a mold. A piece of ⅛-in. strap iron with a U-shaped opening at one end will be useful in placing and smoothing this neat cement cap. The thickness of this cap may be closely controlled by gaging with a piece of thin sheet metal held across the top of a mold at the ends while placing the neat cement.

The dry materials shall be weighed, placed upon a glass or other non-absorbent flat surface, and thoroughly mixed for 1½ min., and a crater formed in the center into which is poured the proper quantity of distilled water, as calculated; the material on the outer edge shall be turned into the crater within 30 sec. After allowing an additional interval of 30 sec. for absorption of the mixing water the operation shall be completed by continuous, vigorous mixing, squeezing, and kneading with the hands for 1½ min. During the operation of mixing, the hands shall be protected by rubber gloves.

Immediately after completion of mixing the mortar shall be placed in the molds as follows:

1. About ¾ in. of mortar shall be pressed into the neat cement, already in place, around the reference plug at each end of a mold. Each end of each mold shall receive 6 tamps of the index finger of the right hand directed toward the end of the mold while the index finger of the left hand holds the mortar from shoving out the top of a mold.

2. The remaining mortar shall then be tamped into the molds in two layers, with the long axes of the bars perpendicular to the front edge of the work table. The bottom layer shall be about ⅔ in. in depth and shall be given 12 tamps with both thumbs working together, ends pointed directly downward, 6 tamps being distributed endwise along a bar in one direction, and the other 6 tamps being likewise distributed but in the opposite direction. After rotating the molds 180 deg., the top layer shall then be tamped in a similar manner except that following the first 6 tamps the excess material shall be redistributed with the trowel and the last 6 tamps made with the face of the thumb. A uniform tamping

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[9] Routine of this particular test is written in the future positive tense in order that possibilities of the procedure may best be considered and criticized as to acceptability for a specification.

pressure of 20 to 25 lb. shall be maintained as closely as possible through these operations.

3. The excess material shall be removed from the tops of the molds with a straightedge and each bar finished with two strokes of the trowel exerting a pressure of approximately 5 lb.

4. The mold shall then be covered with waxed paper, held in place by a sheet metal cover, and immediately placed in the moist closet.

The entire routine of mixing and molding will take about 12 min. distributed over the various operations as follows:

(*a*) Mixing dry materials, $1\frac{1}{2}$ min.
(*b*) Absorption of mixing water, 1 min.
(*c*) Mixing wet materials, $1\frac{1}{2}$ min.
(*d*) Placing in molds, 8 min.

In view of the relatively long time required to prepare these bars it is highly essential that, as closely as possible throughout the whole operation, the room temperature be maintained at 73 ± 3 F. and the relative humidity above 45 per cent, preferably around 60 to 65 per cent.

All bars shall be held in molds in the moist closet for 46 to 48 hr. Immediately after removal from the molds, identification tags, or marks, shall be placed on individual bars and the bars measured and placed in fresh water for 5 days. When 7 days old the bars shall be measured, weighed, and placed in the test solutions and thereafter measured at intervals of 7 days and again weighed upon completion of the test after exposure to the solutions for 28 days, when the bars are 35 days old. Previous to weighing the bars after exposure to the solutions, they shall be lightly brushed, using a 1-in. flat brush of steel wire bristles, five full strokes lengthwise for each of the four sides of a bar. At no time shall other than loose material purposely be removed from a bar by brushing or otherwise. The procedure to follow when weighing any bar shall be to remove superficial water by a towel or absorbent paper and at once weigh. All length changes shall be calculated as percentage change, based on the effective gage length of a bar, assuming as basis of calculations the gage reading when placed in a solution at 7 days. A ratio of solution to volume of bars in any container shall be maintained at about 4:1, and solution strengths shall be expressed in terms of their molarity. Solutions shall be held in covered containers and laboratory temperatures maintained at 73 ± 3 F. Bars shall be stored in the solutions in horizontal positions on slatted racks of wood or noncorrosive metal. Bars shall be so racked as to be an inch or so from the bottom of a container with at least $\frac{1}{4}$-in. space between bars. Solutions shall be renewed by changing completely every 7 days. Duplicate bars from each batch shall be stored in each of the following solutions and a test for sulfate resistance shall consist of no fewer than six bars made on 3 different days:

1. Fresh water
2. Sodium sulfate 0.15 *M* (2.1 per cent)
3. Magnesium sulfate 0.15 *M* (1.8 per cent)

A cement shall be considered to have failed to meet requirements for sulfate resistance if the average expansion of the six bars shall have exceeded 0.02 per cent in any solution, shall have warped badly enough to be appreciably out of line, or shall show change of weight by as much as 5 per cent.

MERRIMAN SLAB TEST

In the Merriman slab test the slabs shall, at the end of 28 days, remain firm, hard and strong and shall show no signs of disintegration or softening. Slight warping or small surface cracks on the edges and corners will not be grounds for rejection. The test procedure is as follows: A sample of 150 g. of the cement is mixed with 43 per cent, by weight of water and stirred for 1 min. by a rotary stirrer in an earthenware jar about 3 in. in diameter and 4 in. high. Near the bottom of this jar is a $\frac{3}{8}$-in. diameter hole closed with a cork. When the stirring is complete, the mixture is rapidly poured, by withdrawing the cork, onto a sheet of moistened paper as made by the Paterson Parchment Paper Company of Bristol, Pa., 30-lb. 400 parchment, white, 24 by 36 in., 34.0 lb. per 500 sheets, or equal, cut to 8 by 10 in., the paper being supported on a clean glass plate 8 by 10 in. in size. On this paper at convenient positions are placed six $\frac{3}{16}$-in. steel balls held in position by paraffin shavings. The poured slab assumes an oval shape about 4 by 8 in. in size. A second glass plate, also having a moistened parchment paper on its face, is then gently lowered into position on the steel balls so as to exclude all air bubbles. A light weight (two soundness pats are sufficient) is then placed on top of the upper glass plate and the assembly carefully put into the moist closet. Twenty-four hours thereafter the assembly is put into the water storage tank (circulating water). After another 24 hr. the glass plates and papers are removed and the slab carefully sawn to size, 2 by 4 in., with a hack-saw and template, it being kept under water except during the sawing process. At this time a small hole is also drilled through the slab at $\frac{1}{2}$ in. from one end and on its center line. This hole serves to suspend the slab in the test solution. The slab then goes back into the water storage tank for 24 hr., when it is removed and hung on a copper hanger in a 2-qt. Mason jar containing 1500 ml. of a 10 per cent, by weight, solution of anhydrous sodium sulfate (Na_2SO_4). The slab is suspended so that its top is 1 in. below the surface of the solution. About 10 drops of an alcohol solution of phenolphthalein are added to the sulfate solution and, after the slab has been placed therein, it is titrated every 24 hr. to the phenolphthalein end point with 6 *N* sulfuric acid. During the test the jars are covered with glass tops without washers, except when the titration is being done. During that process the slab is removed and hung in an empty jar close at hand. A daily record of the quantity of acid added is kept. A sudden increase in the quantity of acid consumed is an indication of failure of the slab before cracks visible to the eye appear. This test is to be made at room temperature.

MERRIMAN SUGAR SOLUBILITY TEST

The sugar solubility of the cement shall not be greater than 8.0 to the phenolphthalein end point, nor greater than 10.0 to the final clear point. These values shall be determined as follows: A sample of about 100 g. of the cement is passed through the No. 200 sieve and put into a glass bottle closed with a rubber stopper. From this bottle 15 g. are then weighed and placed into a Nessler tube containing 100 ml. of a 15 per cent solution of cane sugar in distilled water (commercial granulated sugar such as "Jack Frost"); this solution shall not be more than 3 days old. The tube and its contents are then quickly shaken by hand and placed on a wheel revolving about 60 times per min. At the end of about 1 hr. and 50 min. the mixture is poured into a filter paper and funnel and allowed to filter for 10 min. when the beaker containing the filtrate is removed. In case the filtration time of 10 min. is too short to produce a volume of filtrate of 30 ml., it may be lengthened by shortening the time of shaking, but the total time from the putting of the sample into the solution to the end of the filtration must be exactly 2 hr. (The point has been raised by Mr. Wolochow that the 2-hr. time limit is very unsatisfactory because "some of the cement solutions filter very slowly and the shaking time is therefore reduced inordinately. Also, it practically means that a preliminary test has to be made with each sample to determine filtration time".) Then 25 ml. of the filtrate is titrated with 0.5 *N* HCl in the presence of phenolphthalein and the number of milliliters of phenolphthalein and the number of milliliters of acid to the end point is the first measure of the sugar solubility. At this state of the test, in the case of a thoroughly burned cement which has been kept dry, the solution will be practically clear and only traces of ferric oxide and alumina will be in suspension. In the case of an underburned cement, or one which has been exposed to moisture, the solution will be heavily clouded and the end point must be approached slowly and with caution. When so performed, the phenolphthalein end point can be definitely determined, as the color changes from light pink to yellow. The titration is then continued until the solution is crystal clear and nothing remains in suspension. The total number of milliliters of acid from the beginning of the titration to this final clear point is the second measure of the sugar solubility. This test shall be made at room temperature. In addition to discoloring the quality of the cements as above stated, this test further indicates the character of the hydration products which will be realized in the completed concrete.

PAUL'S WATER FLOC TEST

A 1-g. portion of portland cement, previously dried at 105 to 110 C., is weighed and transferred to a dry 100-ml. test tube fitted with a cork stopper. Exactly 100 ml. of distilled water is then added, while agitating the mixture constantly during the addition of the water. The cork is then tightly fitted into the top of the test tube and sealed with paraffin wax. (At University Farm 12-oz. flat oval bottles fitted with paraffined corks were used and found entirely satisfactory although just a little difficult to clean. The bottles were stood on edge in a horizontal position during the test. Bottles of this type are often times catalogued as "prescription flat ovals" or merely "flat ovals.") The mixture is shaken by hand a few times for 5 sec. and the cement is then dispersed evenly along the entire length of the tube (or bottle) held in a horizontal position. The test tube (or bottle) is left lying in a horizontal position undisturbed in the laboratory at room temperature (70 F.) for a period of 7 days. If a gelatinous precipitate is present, it is transferred onto filter paper, and the test tube (or bottle) is washed three times by decantation with about 40 ml. of distilled water for each decantation, gently agitating the tube each time without disturbing the set cement. (In the laboratory at University Farm the practice that seemed best to serve the purpose was to shake as hard as necessary to remove the floc without disturbing the set cement.) The precipitate is washed five times with distilled water immediately after final decantation. The precipitate is dried, ignited at 1800 F., and weighed. The percentage of floc is calculated on the basis of a 1-g. sample.

APPENDIX IV

PROPOSED METHOD OF TEST FOR FINENESS OF PORTLAND CEMENT BY AIR PERMEABILITY APPARATUS[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. This method of test covers the Blaine air permeability apparatus and procedure for determining the fineness of portland cement in terms of the specific surface expressed as total surface area in square centimeters per gram of cement.

Apparatus

2. (*a*) *Nature of Apparatus.*—The Blaine air permeability apparatus consists essentially of a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The number and size of the pores in a prepared bed of definite porosity is a function of the size of the particles and determines the rate of air flow through the bed. The apparatus, illustrated in Fig. 1, shall consist specifically of the parts described in Paragraphs (*b*) to (*h*).

(*b*) *Permeability Cell.*—The permeability cell shall consist of a rigid cylinder 1.27 ± 0.10 cm. in inside diameter, constructed of glass or noncorroding metal. The top of the cell shall be at right angles to the principal axis of the cell. The bottom of the cell shall form an airtight connection with the top of the manometer. A ledge $\frac{1}{2}$ to 1 mm. in width shall be an integral part of the cell or firmly fixed in the cell 5.0 ± 0.5 cm. from the top of the cell for support of the perforated metal disk.

(*c*) *Disk.*—The disk shall be constructed of noncorroding metal and shall be 0.9 ± 0.1 mm. in thickness, perforated with 25 to 35 holes 1 mm. in diameter equally distributed over its area. The disk shall fit the inside of the cell snugly.

(*d*) *Plunger.*—The plunger shall fit into the cell with a clearance of not more than 0.1 mm. The bottom of the plunger shall have sharp square edges and shall be at right angles to the principal axis. An air vent shall be provided either in the center or on one side of the plunger. The top of the plunger shall be provided with a collar such that when the plunger is placed in the cell and the collar brought in contact with the top of the cell, the distance between the bottom of the plunger and the top of the perforated disk shall be 1.5 ± 0.1 cm.

(*e*) *Filter Paper.*—The filter paper shall be medium retentive, corresponding to type 1, grade B, as prescribed in Federal Specification for Paper; Filtering (UU-P-236). The filter paper disks shall be circular and shall have the same diameter (Note) as the inside of the cell.

NOTE.—Filter paper disks that are too small may leave part of the sample adhering to the inner wall of the cell above the top disk. When too large in diameter, the disks have a tendency to buckle and cause erratic results.

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[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee C-1 on Cement. Published as information, June, 1945.

(*f*) *Manometer.*—The *U*-tube manometer shall be constructed according to the design indicated in Fig. 1, using nominal 9-mm. outside diameter, standard-wall, glass tubing. The top of one arm of the manometer shall form an airtight connection with the permeability cell. The manometer arm connected to the permeability cell shall have a line etched around the tube at the mid-point between the top of the side outlet and the bottom of the manometer and at distances of 1.5 cm., 7.0 cm., and 11.0 cm. above the mid-point. A side outlet shall be provided at 25 to 28 cm. above the bottom of the manometer for use in the evacuation of the manometer arm connected to the permeability cell. A positive airtight valve or clamp shall be provided on the side outlet not more than 5 cm. from the manometer arm. The manometer shall be mounted firmly and in such a manner that the arms are vertical.

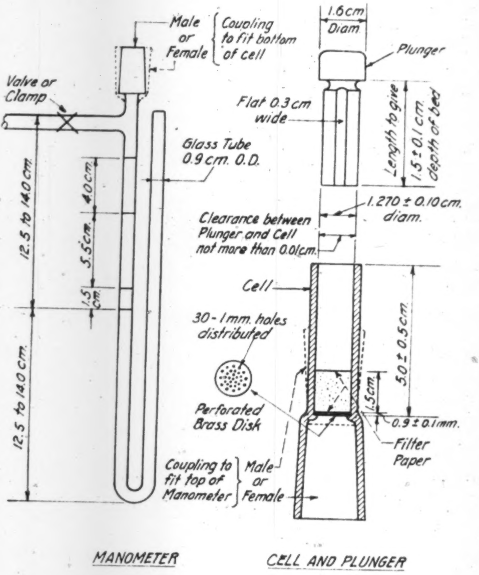
Male or Female
Coupling to fit bottom of cell
1.6cm Diam
Plunger
Valve or Clamp
Flat 0.3 cm wide
Length to give 1.5 ± 0.1 cm. depth of bed
Glass Tube 0.9 cm. O.D.
12.5 to 14.0 cm.
4.0 cm.
5.5 cm.
1.5 cm.
12.5 to 14.0 cm.
1.270 ± 0.10 cm. diam.
Clearance between Plunger and Cell not more than 0.01cm.
Cell
30-1mm. holes distributed
5.0 ± 0.5 cm.
1.5cm.
Perforated Brass Disk
0.9 ± 0.1mm.
Filter Paper
Coupling to fit top of Manometer
Male or Female
MANOMETER
CELL AND PLUNGER

FIG. 1.—Blaine Air Permeability Apparatus.

(*g*) *Manometer Liquid.*—The manometer shall be filled to the mid-point with a nonvolatile, nonhygroscopic liquid of low viscosity and density, such as dibutylphthalate (dibutyl 1,2-benzenedicarboxylate) or a light grade of mineral oil.

(*h*) *Timer.*—The timer shall have a positive starting and stopping mechanism and shall be capable of being read to the nearest 0.5 sec. or less. The timer shall be accurate to 0.5 sec. or less for time intervals up to 60 sec., and to 1 per cent or less for time intervals of 60 to 300 sec.

Calibration of Apparatus

3. (*a*) *Sample.*—The calibration of the air permeability apparatus shall be made using the current lot of National Bureau of Standards' standard sample No. 114. The sample shall be at room temperature when tested.

(*b*) *Bulk Volume of Compacted Bed of Powder.*—The bulk volume of the compacted bed of powder shall be determined by the mercury displacement method as follows:

Place two filter paper disks in the permeability cell, pressing down the edges with a pencil or thin rod until the filter disks are flat on the perforated metal disk; then fill the cell with mercury, removing any air bubbles adhering to the wall of the cell. If the cell is made of material that will amalgamate with mercury, the interior of the cell shall be protected by a very thin film of oil just prior to adding the mercury. Level the mercury with the top of the cell by means of a small glass plate. Remove the mercury from the cell, weigh, and record the weight of the mercury. Remove one of the filter disks from the cell. Using a trial quantity of 2.80 g. of cement (Note 1) compress the cement (Note 2) in accordance with Paragraph (*e*) with one filter disk above and one below the sample. Fill the space remaining in the top of the cell with mercury, remove entrapped air, and level off the top as before. Remove the mercury from the cell, weigh, and record the weight of mercury.

The bulk volume occupied by the cement shall be calculated to the nearest 0.01 cu. cm. as follows:

$$V = \frac{W_A - W_B}{D} \quad \text{..........(1)}$$

where:

V = bulk volume of cement in cubic centimeters,
W_A = grams of mercury required to fill cell, no cement being in cell,
W_B = grams of mercury required to fill the portion of the cell not occupied by the prepared bed of cement in the cell, and
D = density of mercury at temperature of test in grams per cubic centimeter (see Table I).

TABLE I.—DENSITY OF MERCURY AND VISCOSITY OF AIR AT GIVEN TEMPERATURES.

Temperature, deg. Cent.	Viscosity of Air, poises	Density of Mercury, g. per cu. cm.
20	0.0001808	13.55
21	0.0001813	13.54
22	0.0001818	13.54
24	0.0001828	13.54
26	0.0001837	13.53
28	0.0001847	13.53
30	0.0001857	13.52
34	0.0001876	13.51
38	0.0001895	13.50

At least two determinations of bulk volume of cement shall be made, using separate compactions for each determination. The bulk volume value used for subsequent calculations shall be the average of two values agreeing within plus or minus 0.01 cu. cm.

NOTE 1.—It is not necessary to use the standard sample for the bulk volume determination.

NOTE 2.—The prepared bed of cement shall be firm. If too loose or if the cement cannot be compressed to the desired volume, adjust the trial quantity of cement used.

(*c*) *Preparation of Sample.*—The contents of a vial of the standard cement sample shall be enclosed in a 4-oz. jar and shaken vigorously for 2 min. to fluff the cement and break up lumps or agglomerates.

(*d*) *Weight of Sample.*—The weight of the standard sample used for the calibration test shall be that required to produce a bed of cement having a porosity of 0.505 ± 0.005, and shall be calculated as follows:

$$W = 3.15V(1 - e) \quad \text{........(2)}$$

where:

W = grams of sample required,
3.15 = value taken as the specific gravity of portland cement,
V = bulk volume of bed of cement in cubic centimeters, as determined in accordance with Paragraph (*b*), and
e = desired porosity of bed of cement (0.505 ± 0.005).

(*e*) *Preparation of Bed of Cement.*—The perforated disk shall be seated on the ledge in the permeability cell. A filter paper disk shall be placed on the metal disk and the edges pressed down with a pencil or thin rod. A quantity of cement determined in accordance with Paragraph (*d*) and weighed to the nearest 0.01 g. shall be placed in the cell. The side of the cell shall be tapped lightly in order to level the bed of cement. A filter paper disk shall be placed on top of the cement and the cement compressed with the plunger until the plunger collar is in contact with the top of the cell. The plunger shall then be removed slowly.

(*f*) *Permeability Test.*—The permeability cell shall be attached to the manometer tube, making certain that an airtight connection is obtained (Note 1) and taking care not to jar or disturb the prepared bed of cement.

The air in the one arm of the manometer *U*-tube shall be slowly evacuated until the liquid reaches the top mark, and the valve shall then be closed tightly. The timer shall be started as the bottom of the meniscus of the manometer liquid reaches the second (next to the top) mark and shall be stopped as the bottom of the meniscus of liquid reaches the third (next to the bottom) mark. The time interval measured shall be noted and recorded in seconds. The temperature of test shall be noted and recorded in degrees Centigrade.

In the calibration of the instrument, at least three determinations of the time of flow shall be made on each of three separately prepared beds of the standard sample (Note 2). The calibration shall be made by the same operator who makes the fineness determination.

NOTE 1.—If a rubber stopper is used for the connection, it should be moistened with water; if a standard-taper joint is used a little stopcock grease should be applied. The efficiency of the connection can be determined by stoppering the top of the cell attached to the manometer and then partially evacuating the one arm of the manometer; then closing the valve. Any continuous drop in pressure indicates a leak in the system.

NOTE 2.—The sample may be refluffed and reused for preparation of the test bed, provided that it is kept dry and all tests are made within 4 hr. of the opening of the sample.

(*g*) *Calculation of Constants.*—The constants of the apparatus shall be calculated as follows:

$$K_1 = \frac{S_w}{\sqrt{T}} \qquad (3)$$

$$K_2 = \frac{S_w}{\sqrt{\dfrac{T}{n}}} \qquad (4)$$

$$K_3 = \frac{S_w}{\dfrac{\sqrt{e^3 \dfrac{T}{n}}}{1 - e}} \qquad (5)$$

$$K_4 = \frac{S_w}{\dfrac{\sqrt{e^3 \dfrac{T}{n}}}{\rho(1 - e)}} \qquad (6)$$

where:

K_1, K_2, K_3, and K_4 are constants,

S_w = specific surface value of the sample in square centimeters per gram (in this case the assigned air permeability specific surface value of National Bureau of Standards standard sample No. 114 used in the calibration test),

T = time interval in seconds for the meniscus of the manometer liquid to drop from the second to the third marks,

n = viscosity of air in poises at the temperature of test (see Table I),

e = porosity of prepared test bed of cement (calculated by means of Eq. 2), and

ρ = specific gravity of standard sample (assumed to be 3.15).

(*h*) *Recalibration.*—The apparatus shall be recalibrated (Note):

(*1*) At periodic intervals to correct for possible wear on plunger or permeability cell,

(*2*) If any loss in manometer fluid occurs, and

(*3*) If a change is made in the type or quality of the filter paper used for the tests.

NOTE.—It is suggested that a secondary sample be prepared and used as a fineness standard for the check determinations of the instrument between regular calibrations with the standard cement sample.

Procedure

4. (*a*) *Temperature of Cement.*—The cement sample shall be at room temperature when tested.

(*b*) *Size of Test Sample.*—The weight of sample (Note) used for the test shall be the same as that used in the calibration test on the standard sample, except that when determining the fineness of high-early-strength cements the weight of sample shall be that required to produce a test bed having a porosity of 0.530 ± 0.005.

NOTE.—When this method is used for materials other than portland cement, the weight of sample shall be adjusted so that a firm, hard bed is produced by the compacting process.

(*c*) *Preparation of Bed of Cement.*—The test bed of cement shall be prepared in accordance with the method described in Section 3(*e*).

(*d*) *Permeability Test.*—The permeability test shall be made in accordance with the method described in Section 3(*f*), except that only one time-of-flow determination need be made on the one prepared bed of cement.

Calculation

5. (*a*) The appropriate constant and formula shall be used in calculating the specific surface values, as follows:

$$S_w = K_1\sqrt{T} \quad \text{(7)}$$

$$S_w = K_2\sqrt{\frac{T}{n}} \quad \text{(8)}$$

$$S_w = K_3\,\frac{\sqrt{e^3\dfrac{T}{n}}}{1-e} \quad \text{(9)}$$

$$S_w = K_4\,\frac{\sqrt{e^3\dfrac{T}{n}}}{\rho(1-e)} \quad \text{(10)}$$

where:

S_w = specific surface value of test sample in square centimeters per gram,

K_1, K_2, K_3, and K_4 are constants as calculated in Section 3(*g*),

T = measured time interval, in seconds, of manometer drop for test sample,

n = viscosity of air in poises at the temperature of test of the test sample (see Table I),

e = porosity of prepared bed of the test sample, and

ρ = specific gravity of test sample. (For portland cement a value of 3.15 shall be used.)

Equation 7 shall be used when the test temperature of the sample of cement is within plus or minus 3 C. of the temperature of calibration test of the standard fineness sample and the porosity of the test bed is the same as that used for the standard fineness sample.

Equation 8 shall be used when the temperature of test of the sample of cement is not within plus or minus 3 C. of the temperature of calibration test of the standard fineness sample but the porosity of the test bed is the same as that used for the standard fineness sample.

Equation 9 shall be used when the porosity of the test bed is different from that used for the calibration test on the standard fineness sample.

Equation 10 shall be used when this method is applied to materials other than portland cement, using the true value of ρ for the specific gravity of the material tested.

Retests

6. A retest of a sample shall be made if the specific surface value calculated from the first determination is not within the specification requirement. The cement sample shall first be prepared in accordance with Section 3(*c*). The retest shall consist of two determinations made as prescribed in Sections 4 and 5, using a freshly prepared test bed of the sample for each determination. Care shall be exercised in the preparation of the test beds, and precautions shall be taken to insure an airtight connection between the permeability cell and the manometer arm. The fineness value reported shall be the average of the values, calculated from retest determinations agreeing within 2 per cent of each other.

REPORT OF COMMITTEE C-4 ON CLAY PIPE*

Committee C-4 on Clay Pipe held five meetings since its previous formal report to the Society in 1940, as follows: in Atlantic City, N. J., on June 26, 1940, in Chicago, Ill., on June 23, 1941, in Atlantic City on June 24, 1942, in Chicago on May 18, 1943, and in Chicago on May 20, 1944.

Subsequent to the 1944 Annual Meeting, Committee C-4 presented to the Society through Committee E-10 on Standards Tentative Specifications for Standard Strength Clay Sewer Pipe (C 13 – 44 T) to replace Standard Specifications C 13 – 40, and new Tentative Specifications for Extra Strength Clay Pipe (C 200 – 44 T).

These recommendations were accepted[1] by Committee E-10 on August 28, 1944, and the new tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part II.

For some time the clay pipe industry had recognized the urgent need for A.S.T.M. specifications for extra strength clay pipe. While such specifications were under consideration in Subcommittee II of Committee C-4, various other organizations such as the American Association of State Highway Officials, the American Railway Engineering Association, and the Federal Government published their own specifications for extra strength clay pipe. These specifications are excellent, but they differ from each other in small details. A.S.T.M. Specifications C 13 – 44 T and C 200 – 44 T are the results of the efforts of Committee C-4 to bring about a coordination of all specifications for standard strength and extra strength clay pipe which are now available.

There was some opposition to the adoption of the extra strength specification in its present form by a few members of Committee C-4, due to the fact that the dimensions of the pipe were based upon a fixed external diameter instead of on a full internal diameter, as has been the custom before. However, the majority of the committee members felt that the adoption of the specifications represented a definite step forward toward obtaining national uniform standards for clay pipe.

Subcommittee II on Specifications has had the Recommended Practice for Laying Sewer Pipe (C 12 – 19) referred to it for study and revision.

This report has been submitted to letter ballot of the committee, which consists of 25 voting members; 23 members returned their ballots, of whom 20 have voted affirmatively, and 3 negatively.

Respectfully submitted on behalf of the committee,

J. C. Riedel,
Chairman.

Robert G. Scott,
Secretary.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting these recommendations to Committee E-10 on Standards, Committee C-4 reported the following results of the letter ballot vote from a committee membership of 25: C 13 – 44 T, affirmative 19, negative 4, ballots marked "not voting" 1; C 200 – 44 T, affirmative 17, negative 7, ballots marked "not voting" 0.

REPORT OF COMMITTEE C-5

ON

FIRE TESTS OF MATERIALS AND CONSTRUCTION*

Since the preceding report in June, 1943, Committee C-5, on Fire Tests of Materials and Construction has held one meeting, on June 26, 1944, in New York, N.Y. Arrangements for holding a meeting this year were canceled.

The committee now consists of 46 members, of whom 21 are classified as producers, 7 as consumers, 15 as general interest members, and 3 as consulting members. The by-laws of the committee were amended to provide for the election of experts, whose advice and cooperation are desired, to serve as consulting members, entitled to vote in the subcommittees to which they are appointed.

TENTATIVE METHOD CONTINUED AS TENTATIVE

The Tentative Method of Test for Fire-Retardant Properties of Wood (C 160 - 41 T),[1] which is based on the use of the modified crib test, has been continued as tentative[2] in order to obtain are cord of a larger volume of use of the method and to develop further sampling requirements. The subcommittee recommended a revision in the method, but at a later meeting this was withdrawn and the recommendation made that the method be continued as tentative without revision. This recommendation has been submitted to letter ballot of the committee which consists of 42 members; 33 members returned their ballots, of whom 29 have voted affirmatively, 0 negatively, and 4 members marked their ballots "not voting."

Fire Tests of Building Construction.—Experience with the Standard Methods of Fire Tests of Building Construction and Materials (C 19 - 41) has indicated in general that they serve satisfactorily in rating the fire resistance of building constructions such as floors, walls, partitions, and columns. Subcommittee I has recommended to the committee a closer definition of the time-temperature fire exposure curve and the area thereunder taken to a base line of 20 C. (68 F.) defined at 5-minute intervals. It is also considering certain modifications of the test procedure applicable to roof constructions but not to floors. A number of fire tests of roof constructions have been conducted as a source of information.

Fire Tests of Window Assemblies.—Proposed Tentative Methods of Fire Tests of Window Assemblies were presented at the 1943 Annual meeting of the Society but were not accepted, largely in deference to comments by a representative of the Metal Window Institute. During the past year, consideration has been given to revision of the former proposal to define within as close limits as practical with present testing equipments, the fire exposure conditions for window assemblies and performance requirements. It is expected that revised methods will be submitted to Committee E-10 on Standards for publication as tentative subsequent to the Annual Meeting.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 Book of A.S.T.M. Standards, Part II.

[2] See Editorial Note, p. 202.

Progress has been made on the preparation of a Proposed Tentative Method of Conducting Fire Tests of Wood using the fire tube apparatus developed by the U. S. Forest Products Laboratory. The equipment and method of test were defined but the proposal was withheld pending development of requirements for sampling. Such requirements would have to be applicable to stock partially impregnated with chemicals as well as to more nearly full treatment throughout the cross-section.

Fire Tests of Ceiling Constructions.—Attention has been given to the development of a Method of Conducting Fire Tests of Ceiling Constructions as distinct from floor constructions, and a proposed method was submitted by Subcommittee I. Action thereon was withheld by the committee pending the conduct of further fire tests with ceiling constructions. The results of three tests have been made available and further tests are in progress.

Fire Tests of Acoustical and Similar Finishes.—In developing methods for conducting fire hazard tests of acoustical and similar materials, further information from flame spread tests conducted at the Underwriters' Laboratories and the National Bureau of Standards have been obtained but requirements relating to details of the equipment and methods of test have not as yet been given consideration.

Fire Tests of Roof Coverings.—A new Subcommittee VIII (H. M. Robinson, chairman) was formed to consider the preparation of a Method of Conducting Fire Tests of Roof Coverings, and to determine the classifications of the materials and combination of materials employed. A meeting of the subcommittee has been held at which it was decided to give consideration to the fire test procedure employed by the Underwriters' Laboratories as a basis for a method of fire tests of roof coverings.

Definition of Terms Relating to Fire Resistance.—Subcommittee V has given consideration to the development of definitions of some of the more common terms in present or prospective use in the committee's standards. An experimental study was made of the British test and definition of an incombustible material, the method involving progressive heating up to a temperature of 750 C. (1382 F.) in $1\frac{1}{2}$ hr. Somewhat more consistent results were obtained by heating the equipment up to the final temperature (750 C.) before introducing the sample. A definition based on the modified method is under consideration by the committee.

This report has been submitted to letter ballot of the committee which consists of 42 members; 33 members returned their ballots, of whom 31 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

S. H. INGBERG,
Chairman.

H. M. ROBINSON,
Secretary.

EDITORIAL NOTE

On June 27, 1945, the Administrative Committee on Standards accepted the recommendation of Committee C-5 that the Tentative Method of Test for Fire-Retardant Properties of Wood (C 160 - 41 T) be continued in its present form.

REPORT OF COMMITTEE C-7

ON

LIME*

Committee C-7 on Lime held one meeting during the year, on June 28, 1944, in New York, N. Y.

The total membership at present is 53, of whom 25 are classified as producers, 6 as consumers, and 22 as general interest members.

I. REVISION OF TENTATIVE

The committee recommends that the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 – 38 T)[1] be revised as indicated in the Appendix which revision includes changes in the method for determination of consistency and the addition of new tests for popping and pitting and for water retention of hydrated lime.[2]

II. TENTATIVE REVISION OF STANDARD

The committee recommends the following method for calculating unhydrated oxides on the as-received basis for publication as a tentative revision[2] of the Standard Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 – 44):[1]

New Section.—Add the following new section:

27. *Unhydrated Oxides Calculated on As-Received Basis:* (*a*) Determine the percentages of free water, combined water, CO_2, SO_3, CaO, and MgO in accordance with the Standard Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (A.S.T.M. Designation: C 25 – 44).

(*b*) Calculate the percentage of unhydrated oxides on the as-received basis, as follows (Notes 1, 2 and 3):

(*1*) Calculate the CaO equivalents of the CO_2 and SO_3,

(*2*) Subtract the sum of these CaO equivalents from the total CaO,

(*3*) Calculate the H_2O equivalent of the remaining CaO,

(*4*) Subtract this value for H_2O from the combined water as determined,

(*5*) Calculate the MgO equivalent of the remaining combined water, and

(*6*) Subtract this MgO equivalent from the total MgO as determined to obtain the percentage of unhydrated MgO on the as-received basis.

NOTE 1: *Example of Calculation.*—The calculations involved in determining the percentage of unhydrated oxides on the as-received basis are illustrated in Table I.

NOTE 2.—This method for calculating the percentage of unhydrated oxides is intended primarily for use with type S hydrated lime.

NOTE 3.—It is recognized that the results of this method of calculation may not be in strict accord with the actual composition of the material. Experience indicates, however, that these results provide an index to the performance of the material in practice. The value obtained by this calculation shall be reported to the nearest 0.5 per cent.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 53 members, with the results shown in Table II.

Contingent upon approval of the above recommendations, Committee C-7

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 Book of A.S.T.M. Standards, Part II.

[2] See Editorial Note, p. 205.

TABLE I.—EXAMPLE OF CALCULATION.

Compound	Values Determined from Chemical Analysis, per cent	Residual Values	Factors	Calculated Values, per cent
CO_2	0.40		× 1.275	= equivalent CaO = 0.51
SO_3	0.48		× 0.700	= equivalent CaO = 0.34
CaO	42.79 − (0.51 + 0.34 = 0.85)	= 41.94	× 0.3213	= equivalent H_2O = 13.48
H_2O	25.09 − 13.48	= 11.61	× 2.238	= equivalent MgO = 25.98
MgO	30.68 − 25.98			= unhydrated MgO = 4.70

plans to submit to Committee E-10 on Standards proposed Tentative Specifications for Hydrated Lime for Masonry Purposes and for Special Finishing Hydrated Lime, as well as a proposed tentative revision of the Standard Specifications for Normal Finishing Hydrated Lime (C 6 – 44).

Committee C-7 recommends that all other standards and tentative standards under its jurisdiction be continued in their present status without revision.

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE			
Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 – 38 T):			
Revision of Section 6 (a)	22½	2	3½
Addition of Test for Popping Pitting of Hydrated Lime	18	4½	5½
Addition of Test for Water Retention of Hydrated Lime	21½	3	3½
II. TENTATIVE REVISION OF STANDARD			
Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 – 44):			
Method for Calculating Unhydrated Oxides on the As-Received Basis	21½	4	2½

Activities of Subcommittees

Advisory Committee (W. C. Voss, chairman) held a meeting in New York, N. Y., during which the work and responsibilities of each of the subcommittees for the year were planned. A revised procedure for subcommittee work was recommended to Committee C-7 as an amendment to its By-Laws and has since been adopted.

Subcommittee II on Structural Lime (Howard R. Staley, chairman) held a meeting in New York, N. Y., and another in Cambridge, Mass., on February 28, 1945. At the February meeting consideration was given to Specifications for Masons Hydrated Lime and for Type S Finishing Lime. Action was also taken at that time to revise the Specifications for Type N Finishing Lime by eliminating the old soundness test and substituting the new test for popping and pitting.[3] The specifications, together with the proposed tentative revision of Standard Specifications C 6 – 44 have been recommended for letter ballot of the entire committee.

Subcommittee III on Lime for the Chemical Industries (R. W. McAllister, chairman) held one meeting in New York, N. Y. The subcommittee has in hand the preparation of the section on special requirements for incorporation in the master specifications. No comments or suggestions were received from the members of Committee C-7 to whom the form, approved at the June, 1944, meeting, was submitted. A final draft, incorporating whatever additional special requirements appear advisable, will be ready for letter ballot shortly.

Subcommittee V on Methods of Test for Lime and Lime Products (C. R. Austin, chairman) held two meetings during the year, one in New York, N. Y., and the other in Cambridge, Mass., on February 28, 1945. The chief work before the subcommittee has been the preparation of methods of test for popping and pitting, water retentivity, unhydrated oxides, and plasticity tests. The subcommittee recommended these methods for references to letter ballot of the committee looking toward their publication as tentative.

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[3] See p. 206.

Subcommittee VIII on Nomenclature and Definitions (Nathan C. Rockwood, chairman succeeding W. V. Brumbaugh resigned) held one meeting in New York, N. Y., at which it completed the Tentative Definitions of Terms Relating to Lime (C 51 – 44 T)[1] which were accepted at the 1944 Annual Meeting.

Subcommittee IX on Research Problems (C. J. Koehler, chairman) did not hold a meeting during the year but has circulated replies to questionnaires to the subcommittee for discussion on the subject of testing limes for water retentivity.

This report has been submitted to letter ballot of the committee which consists of 53 members; 30 members returned their ballots, of whom 30 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

W. C. VOSS,
Chairman.

L. K. HERNDON,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 6, a proposed revision of the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 – 38 T) and a proposed tentative revision of the Standard Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 – 44) as referred to in the report were submitted by Committee C-7 and accepted by the Administrative Committee on Standards on June 27, 1945. The revised tentative and the tentative revision appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part II.

APPENDIX

PROPOSED REVISION OF THE TENTATIVE METHODS OF PHYSICAL TESTING OF QUICKLIME AND HYDRATED LIME (C 110 - 38 T)[1]

Section 6 (a).—Change from its present form: namely,

6. (*a*) *Procedure.*—Standard consistency of lime putty shall be measured as follows: About 300 g. of hydrated lime shall be mixed with sufficient water to form a thick putty and stirred with a trowel or spatula for 2 or 3 min. to insure intimate mixing. After aging in a vessel covered with a damp cloth for not less than 16 nor more than 24 hr., this putty shall again be stirred for 2 or 3 min. and a sufficient quantity placed in the ring mold resting on the glass base plate. The mold shall be placed with its larger end resting on the base plate and, after filling, the lime putty shall be struck off flush with the top of the mold. The lime putty, confined in the ring mold resting on the plate, shall then be centered under the rod of the modified Vicat apparatus, Fig. 1. The plunger end, *C*, shall then be brought in contact with the surface of the lime putty and an initial reading taken. The rod shall then be released and the final reading shall be taken 30 sec. after the plunger is released.

to read as follows:

6. (*a*) *Procedure.*—About 300 g. of hydrated lime shall be mixed with sufficient water to form a thick putty and stirred with a trowel or spatula for 2 or 3 min. to insure intimate mixing. If no soaking of the putty is required, the consistency shall be adjusted immediately by suitable additions of water to conform to the requirements for penetration prescribed in Paragraph (*b*). If soaking is required, the putty, after initial wetting, shall be stored in a vessel covered with a damp cloth for not less than 16 nor more than 24 hr. After soaking, this putty shall again be stirred for 2 or 3 min. and the consistency then determined. To determine consistency, the mold shall be placed with its larger end resting on the glass base plate and filled with the lime putty, after which the putty shall be struck off flush with the top of the mold. The lime putty, confined in the ring mold resting on the plate, shall then be centered under the rod of the modified Vicat apparatus (Fig. 1). The plunger end, *C*, shall then be brought in contact with the surface of the lime putty and an initial reading taken. The rod shall then be released and the final reading shall be taken 30 sec. after the plunger is released.

New Sections.—Add the following new Sections 12 to 16, covering tests for popping and pitting and for water retention of hydrated lime:

POPPING AND PITTING OF HYDRATED LIME

12. *Gaging Plaster.*—The gaging plaster used for the popping and pitting test shall have a setting time of not more than 1 hr. when tested in accordance with Sections 25 and 26(*a*) of the Standard Methods of Testing Gypsum and Gypsum Products (A.S.T.M. Designation: C 26).[2] The gaging plaster shall be tested without lime in the manner described in Section 13 to ensure its freedom from pops. If any pops are found, another lot of gaging plaster shall be provided which is free from pops when subjected to this test.

13. *Procedure.*—(*a*) Mix 100 g. of hydrated lime with sufficient water to bring to such a consistency as to give a penetration of 20 ± 5 mm. when tested in accordance with Section 6. Mix into this putty, 25 g. of gaging plaster (Section 12), adding more water as required to maintain workable consistency. Spread on a glass plate to make a pat at least 6 by 8 in. by approximately $\frac{1}{8}$ in. in thickness. Trowel to a smooth finish. Allow to stand overnight.

(*b*) Place the specimen and plate on a rack in the steam bath so that water is not in contact with the specimen to be tested. A sloping cover shall be provided above the specimen to prevent condensed steam from dripping onto the surface of the specimen. Raise the temperature of the water in the steam bath to boiling and maintain at boiling for 5 hr. Remove the specimens from the bath and examine for pops and pits.

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[1] For an explanation of this revision, see p. 203.

[2] 1944 Book of A.S.T.M. Standards, Part II.

WATER RETENTION OF HYDRATED LIME

14. *Proportioning and Mixing.*—The mortar tested shall be composed of 500 g. of lime and 1500 g. of standard Ottawa sand conforming to Section 20 of the Tentative Specifications for Masonry Cement (A.S.T.M. Designation: C 91 – 44 T).[2] If hydrated lime putty is used, that weight of putty shall be used which is equivalent to 500 g. of the dry hydrated lime. The mortar shall be mixed in a nonabsorbent bowl of about 1-gal. capacity. A measured quantity of water shall be poured into the bowl which has previously been wiped with a damp cloth. The 500 g. of lime shall then be added and stirred into the water with the fingers of one hand until the lime is thoroughly wetted (50 to 100 g. of the sand may be mixed with the dry hydrated lime before the latter is added to the water.) If hydrated lime putty is used, it shall be diluted with a measured amount of water to make a homogeneous slurry, by stirring the mixture with the gloved fingers of one hand. Approximately one half of the sand shall then be added and the stirring continued for 30 sec. The remainder of the 1500 g. of sand shall then be added and the mortar mixed for 75 sec. by vigorous and continuous stirring, squeezing, and kneading with one hand. The mortar shall then be allowed to stand for not more than 15 min. with a cover on the bowl and then shall be remixed for another 60 sec. immediately before testing for flow. During the operation of mixing, the hands shall be protected by rubber gloves.

15. *Consistency: (a) Apparatus.*—The flow table and flow mold used for the measurement of the consistency of the mortar shall conform to the requirements specified in Section 19 (*g*) and (*h*) of A.S.T.M. Specifications C 91 – 44 T.

(*b*) *Procedure.*—The flow table top shall be carefully wiped dry and the flow mold placed at the center. Immediately after completing the mixing operation, the mold shall be filled with mortar gently pressed into place by the finger tips to insure uniform filling. The mortar shall be smoothed off level with the top of the mold by aid of a trowel, and the mold removed. Immediately the table shall be dropped through a height of ½ in., 25 times in 15 sec. The flow is the resulting increase in diameter of the mortar mass, expressed as the percentage of the original diameter. The mortar may be adjusted, if the flow is below 100 per cent, by additions of water until the flow is within the range from 100 to 115 per cent. Each adjustment shall be made by returning the mortar to the original mixing bowl, adding water, and then mixing for 135 sec. by vigorous and continued stirring, squeezing, and kneading with one hand. If the flow of the original mortar is greater than 115 per cent, a new batch shall be prepared.

16. *Water Retention Test: (a) Apparatus.*—For the water retention test, an apparatus essentially the same as that illustrated in Fig. 1 of A.S.T.M. Specifications C 91 – 44 T shall be used. This apparatus consists of a water aspirator controlled by a mercury column relief and connected by way of a three-way stopcock to a funnel upon which rests a perforated dish. A mercury manometer should be connected, as shown, to provide a check on the vacuum. A rubber gasket is sealed to the top of the funnel and shall be kept wet during a test to insure a seal between the funnel and dish. The perforated dish shall be made of nonabsorbent material. Hardened filter paper equivalent to Carl Schleicher & Schuell filter paper No. 575 shall be used. It shall be of such diameter that it will lie flat and completely cover the bottom of the dish.

(*b*) *Procedure.*—Immediately after making the flow test on the mortar which has been mixed and tested as described in Sections 14 and 15, the mortar on the flow table shall be remixed for 30 sec. with that remaining in the mixing bowl. Immediately after remixing, the mortar shall be uniformly distributed, without compacting, over the sheet of dampened filter paper in the perforated dish and the surface leveled off flush with the rim of the dish by drawing a straightedge across the dish with a slightly sawing motion. The dish shall then be seated on the wetted gasket, and with the mercury relief column previously adjusted so as to maintain a vacuum of 2 in., the stopcock shall be turned to apply the vacuum to the funnel. After suction for 60 sec., the stopcock shall be quickly turned to expose the funnel to atmospheric pressure. The contents of the dish shall then be immediately removed by means of a putty knife or square-end spatula and placed in the mold on the flow table. As each "knifefull" of mortar is placed in the mold, it shall be puddled with glove-covered fingers. When the mold is filled, the mortar shall be smoothed off level with the top of the mold and the flow determined as previously. The entire operation shall be carried out without interruption and as quickly as possible and shall require not more than 30 min. for completion, starting from the completion of the mixing of the mortar for the first flow determination.

(*c*) *Calculation.*—Calculate the water retention value for the mortar as follows:

$$\text{Water retention value} = \frac{A}{B} \times 100$$

where:

A = flow after suction, and

B = flow immediately after mixing.

REPORT OF COMMITTEE C-8

ON

REFRACTORIES*

Because of the war situation, Committee C-8 on Refractories held but one meeting during the year, at Mellon Institute, Pittsburgh, Pa., on September 28, 1944. The committee was active, however, and transacted additional business by correspondence.

A number of recommendations, resulting from actions of the committee at its September meeting and subsequent letter ballot, were submitted to the Society through Committee E-10 on Standards. These recommendations which are listed in Table I together with the results of the letter ballot vote in Committee C-8 were accepted by Committee E-10 on March 14, 1945, and the new and revised tentatives[1] were assigned the A.S.T.M. serial designations indicated.

W. S. Debenham, representing Carnegie-Illinois Steel Corp., was elected to committee membership during the year. The following members severed their connections with the committee during the year: E. E. Callinan, R. K. Hursh, J. T. MacKenzie, F. H. Norton, and D. L. Ogden.

Two new subcommittees were established and one inactive one was reestablished. A new Subcommittee on Special Refractories (M. C. Booze, chairman) is to prepare information on methods of of test and specifications pertaining to such refractory products as mullite, zircon, basic refractories, and other products. The new Subcommittee on Petrography (H. M. Kraner, chairman) will renew the work of the Section on Microscopy which was disbanded a number of years ago.

TABLE I.—RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS, INCLUDING RECORD OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. New Tentatives			
Test for Bonding Strength of Air-Setting Refractory Mortar (Wet Type) (C 198 - 45 T)	30	0	1
Test for Refractoriness of Air-Setting Refractory Mortar (Wet Type) (C 199 - 45 T)	30	0	1
Test for Thermal Conductivity of Refractories (C 201 - 45 T)	29	1	1
Test for Thermal Conductivity of Insulating Fire Brick (C 182 - 45 T)	30	0	1
Test for Thermal Conductivity of Fireclay Refractories (C 202 - 45 T)	29	0	2
II. Revision of Tentatives			
Spec. for Air-Setting Refractory Mortar (Wet Type) for Boiler and Incinerator Service (C 178 - 45 T)	30	0	1
Classification of Insulating Back-Up Block and Insulating Fire Brick (C 155 - 45 T)	30	0	1
III. Tentative Revision of Standard			
Def. of Terms Relating to Refractories (C 71 - 42):			
Definition of Air-Setting Refractory Mortar	26	2	3
Definition of Fireclay Plastic Refractory	27	2	2
IV. Withdrawal of Tentatives			
Spec. for Air-Setting Refractory Mortars (Wet Type) for Boiler and Incinerator Services (C 178 - 44 T)	30	0	1
Test for Thermal Conductivity of Insulating Fire Brick (C 182 - 43 T)	31	0	0

The Section on Consistency and Plasticity under Subcommittee III on Tests was reorganized as a new Section for Tests on Mortars and Plastic Refractories (R. S. Bradley, chairman). The principal work for the former section was in the field relating to mortars and plastic refractories, and the change was made in order to include work on additional methods of test for these two products.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] These methods were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part II.

The Section on Load (J. D. Sullivan, chairman) was reestablished after several years inactivity.

The Section on Slagging is to remain inactive for the present.

The Regulations Governing Committee C-8 were revised to allow for the appointment and approval of personnel of sections of subcommittees in the same manner as is now prescribed for subcommittee members. This revision involves inserting the words "and sections of subcommittees" in Section 1 of Article V and Section 4 of Article VII.

Committee C-8 adopted the following resolutions:

> It is the declared policy of Committee C-8, subject to exception for special reasons, that an appointment to the chairmanship of a subcommittee or section shall be renewed for at least one two-year term, but that it shall not be extended beyond five two-year terms.
>
> It is the declared policy of Committee C-8 that one member of the Advisory Committee be replaced at the end of each two-year term.

I. ADOPTION OF TENTATIVE METHODS AS STANDARD

Tentative Method of Panel Test for Resistance to Thermal and Structural Spalling of Fireclay Plastic Refractories (**C 180 - 43 T**).[2]—In 1942 this method was included as part of the Tentative Specifications for Fireclay Plastic Refractories for Boiler and Incinerator Services (C 176 - 42 T). In 1943 the method was separated from the specifications and published separately as tentative. Since this method has been found satisfactory, Committee C-8 recommends that it be approved for reference to letter ballot of the Society for adoption as standard.

Tentative Method of Test for Workability Index of Fireclay Plastic Refractories (**C 181 - 43 T**).[2]—This tentative method also was formerly a part of Specifications C 176 from which it was separated in 1943. Editorial changes were approved by Committee C-8 to incorporate an improved means of measuring the length of the specimen before and after the impacts to which it is subjected during the test. The committee accordingly recommends that the method be approved for reference to letter ballot of the Society for adoption as standard, with the minor editorial revisions.

II. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

Method of Panel Test for Resistance to Thermal and Structural Spalling of Refractory Brick (**C 38 - 42**).[2]—The tentative revision[2] of this method, published in 1943, concerns Sections 4, 5, and 7, and specifies increased accuracy in weighing the test brick, a narrower permissible range of temperature variation during the preheating, and deletion of instructions for rearranging the test brick when a second test is conducted on test specimens. As no objections have been received, the committee recommends that this tentative revision be approved for reference to letter ballot of the Society for adoption as standard.

Method of Panel Test for Resistance to Thermal and Structural Spalling of High Heat Duty Fireclay Brick (**C 107 - 42**), and *Panel Test for Resistance to Thermal and Structural Spalling of Super Duty Fireclay Brick* (**C 122 - 42**).[2]—Section 4 (*d*) of each of these two methods was tentatively revised in 1943. In this section closer limits for furnace gas pressure during preheating were specified, and references to the use of gas or oil as a fuel were deleted. Since data obtained in spalling tests are in good agreement whether gas or oil is used as a fuel, and since this was one of the purposes of the tentative revision, the committee has approved editorial deletion of all other reference to the use of gas as a fuel in these methods. No criticism has been received. The committee recommends that both of these tentative revisions be approved for reference to letter ballot of the Society for adoption as standard.

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[2] 1944 Book of A.S.T.M. Standards, Part II.

III. REVISION OF STANDARDS, IMMEDIATE ADOPTION

Methods of Chemical Analysis of Refractory Materials (**C 18 - 41**).[2]—It has been found that Section 54 of these methods does not provide reliable results for the ignition loss of chrome ore and chrome refractories. Apparently close control of atmosphere in which operation takes place must be maintained. The committee accordingly recommends that this section be withdrawn and asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

Definitions of Terms Relating to Refractories (**C 71 - 42**).[2]—The committee recommends that the definition for "high-temperature bonding mortar" be withdrawn inasmuch as it has been replaced by the definition of air-setting refractory mortar which, as given under the report of Subcommittee VI has been accepted for publication as tentative, and asks for a nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 33 members; 31 members returned their ballots with the results shown in Table II.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Industrial Survey (L. C. Hewitt, chairman) is supervising revisions of surveys on refractories used in coke ovens, for open-hearth furnaces, and in the lead industry. The open-hearth survey has been completed by W. S. Debenham of Carnegie-Illinois Steel Corp. and is now being reviewed by the Editorial Subcommittee. Two new surveys are planned. It is hoped that H. A. Arndt, Consolidated Gas and Electric Co., will undertake a survey of refractory service conditions in the gas industry and that E. E. Callinan will prepare a survey on steel-mill pouring pit refractories. It is not expected that these surveys, other than the open-hearth, will be completed until after the war period.

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. ADOPTION OF TENTATIVE METHODS AS STANDARD			
Panel Test for Resistance to Thermal and Structural Spalling of Fireclay Plastic Refractories (C 180 - 43 T)	29	0	2
Test for Workability Index of Fireclay Plastic Refractories (C 181 - 43 T)	29	1	1
II. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Panel Test for Resistance to Thermal and Structural Spalling of Refractory Brick (C 38 - 42)	30	0	1
Panel Test for Resistance to Thermal and Structural Spalling of High Heat Duty Fireclay Brick (C 107 - 42)	30	0	1
Panel Test for Resistance to Thermal and Structural Spalling of Super Duty Fireclay Brick (C 122 - 42)	30	0	1
III. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Chemical Analysis of Refractory Materials (C 18 - 41)	28	0	3
Def. of Terms Relating to Refractories (C 71 - 42)	29	0	2

Subcommittee II on Research (R. B. Sosman, chairman), as indicated, is now under the chairmanship of Mr. Sosman.

At the last meeting of the Advisory Committee, this appointment was made in view of the newly adopted policy of Committee C-8 of changing committee personnel in order to keep new life blood in all groups.

Subcommittee III on Tests (F. A. Harvey, chairman) is composed of the chairmen of the several sections described below. This subcommittee, in cooperation with the Editorial Subcommittee, separated the test methods from the Specifications for Air-Setting Refractory Mortar (Wet Type) for Boiler and Incinerator Services (C 178 – 43 T) and prepared the two new methods for determining bonding strength and refractoriness for this type of mortar. All test methods under the jurisdiction of Committee C-8 are being reviewed in order to insure that all equipment is adequately described. Further activities of the subcommittee are discussed under the individual sections.

Section A on Load (J. D. Sullivan, chairman) was reestablished at the last meeting of the Advisory Committee, and is giving consideration to setting up load-test schedules for brick not now covered, particularly silica and the various basic and neutral products. Questionnaires have been sent out to 26 laboratories, believed to have load-test equipment, to learn how they are currently conducting such tests.

Section B on Spalling (R. E. Birch, chairman) reviewed the tentative revisions issued in 1943 for the several spalling procedures (Methods C 38, C 107, and C 122) and recommended that these revisions be adopted as standard. The adoption as standard of the Test for Workability Index of Fireclay Plastic Refractories (Method C 181 – 43 T) with editorial revisions was also recommended by this subcommittee.

Section C on Temperature (S. M. Phelps, chairman) was under the chairmanship of R. B. Sosman prior to the last meeting of the Advisory Committee. During the year Mr. Sosman presented to the American Ceramic Society a paper entitled "Significance of the P.C.E. Test of Refractories and Refractory Raw Materials."

The matter of standardizing cone 32½ at the National Bureau of Standards has been postponed until after the war.

Section D on Slagging was declared temporarily inactive at the last meeting of the Advisory Committee.

Section E on Analysis (L. J. Trostel, chairman) prepared a number of editorial changes in the Methods of Chemical Analysis of Refractory Materials (C 18 – 41) which were approved by the committee.

Section F on Tests on Refractory Insulation (W. R. Kerr, chairman) is considering the desirability of extending the classes in the Tentative Classification of Insulating Back-Up Block and Insulating Fire Brick (C 155 – 41 T) to include group 30 material. The Refractories Fellowship at Mellon Institute studied the properties of two brands of insulating fire brick which were manufactured for 3000 F. service. This information will be used in connection with the above-mentioned possible revision of Classification C 155.

Section G on Porosity and Permanent Volume Change (C. E. Fulton, chairman) was inactive during the year.

Section H on Tests for Mortars and Plastic Refractories (R. S. Bradley, chairman) is a new section formed at the last Advisory Committee meeting to replace the former Section H on Consistency and Plasticity. The principal work of the former section was in mortars and plastic refractories. The new section will work on other methods of test for these two refractory products.

Section I on Petrography (H. M. Kraner, chairman) is in the course of organization and is getting a program lined up.

Subcommittee IV on Heat Transfer (R. H. Heilman, chairman) prepared the three new tentative methods of test for thermal conductivity to replace Method C 182 - 43 T. Use was made of information presented in a paper by T. C. Patton and C. L. Norton, Jr. on "Measurement of the Thermal Conductivity of Fireclay Refractories."[3]

Subcommittee V on Precision and Tolerance (R. A. Heindl, chairman *pro tem*) has been preparing paragraphs on sampling for inclusion in various specifications to be presented at the next meeting. In the revision of subcommittees, E. E. Callinan was appointed chairman of Subcommittee V, but his subsequent change of employment automatically dropped him from membership on Committee C-8, and R. A. Heindl is serving as chairman until Mr. Callinan resumes membership on the committee.

Subcommittee VI on Nomenclature (R. A. Heindl, chairman), prior to the last meeting, was under the chairmanship of M. E. Holmes. The subcommittee prepared the following definitions for air-setting refractory mortar and fireclay plastic refractory, which, as mentioned earlier in this report, were accepted by Committee E-10 for publication as a tentative revision of the Standard Definitions of Terms Relating to Refractories (C 71 - 42):

Air-Setting Refractory Mortar.—A finely ground refractory material prepared in the wet or dry condition which, when tempered with the required amount of water, forms a mortar that will, upon drying, develop a strong air-set bond between refractory brick and maintain a bond when heated to furnace temperature.

Fireclay Plastic Refractory.—A fireclay material tempered with water and suitable for ramming into place to form a monolithic furnace lining that will attain satisfactory physical properties when subjected to the heat of furnace operation.

The subcommittee is now considering a revision of the definition for fire clay as well as a change in the new definition for air-setting refractory mortar.

Subcommittee VII on Specifications (G. A. Bole, chairman) prepared the new Tentative Specifications for Air-Setting Refractory Mortar (Wet Type) for Boiler and Incinerator Service (C 178 - 45 T) which replace Tentative Specifications C 178 - 44 T.

Subcommittee VIII, Editorial (L. J. Trostel, chairman) handled all routine matters in connection with editorial changes in standards and editorial form of new standards and industrial surveys.

Subcommittee IX on Classifications (S. M. Swain, chairman) recommended a revision in the Classification of Insulating Back-Up Block and Insulating Fire Brick (C 155 - 41 T) so as to eliminate any reference to insulating back-up block, which, as mentioned earlier in this report, was accepted by Committee E-10. Careful consideration was given to suggested changes in the Classification of Fireclay Refractories (C 27- 41), but the committee decided that no change should be made in the classification at this time.

This report has been submitted to letter ballot of the committee, which consists of 32 members; 31 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. D. SULLIVAN,
Chairman.

L. J. TROSTEL,
Vice-Chairman.

S. M. PHELPS,
Secretary

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[3] *Journal*, Am. Ceramic Society, October, 1943.

REPORT OF COMMITTEE C-12

ON

MORTARS FOR UNIT MASONRY*

Since presenting its 1944 report, Committee C-12 on Mortars for Unit Masonry has held one meeting in New York, N. Y., on June 29, 1944. At this meeting it was voted to hold a meeting of the committee in conjunction with the spring meeting of the Society. Early in 1945, however, the officers of the committee canvassed the members on the advisability of holding a meeting and, as a result of this canvass, the contemplated spring and summer meetings of the committee have been canceled.

The membership of the committee now consists of 35, of whom 13 are classified as producers, 7 as consumers, and 15 as general interest members.

Activities of Subcommittees

The activities of the subcommittees have been materially restricted during the past year due to the limited amount of time that members could devote to this work and the drastic reduction in the staffs of cooperating research laboratories; however, some progress has been made.

A proposed draft of specifications for mortars for unit masonry has been distributed to the members of Subcommittee III on Specifications and Methods of Test for Mortar (H. C. Plummer, acting chairman) and comments and suggested revisions of the specifications have been submitted by most of the members of the subcommittee. These revisions will be referred by correspondence to all members of the subcommittee and it is hoped that the specifications will soon be ready for submittal to the main committee.

A letter ballot in Subcommittee III on a proposal for the adoption as standard of the Tentative Specifications for Mortar for Reinforced Brick Masonry (C 161 – 44 T) resulted in a number of suggested revisions in the specifications which are now under consideration. As a result, Specifications C 161 are being continued as tentative.

The Working Subcommittee on Efflorescence (P. L. Rogers, chairman) has conducted research on methods of test for efflorescence of mortars and reports progress, particularly through the use of efflorwicks (standard clay units).

This report has been submitted to letter ballot of the committee which consists of 35 members; 27 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

Theodore I. Coe,
Chairman.

Harry C. Plummer,
Secretary.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

REPORT OF COMMITTEE C-15
ON
MANUFACTURED MASONRY UNITS*

Committee C-15 on Manufactured Masonry Units held a meeting on June 29, 1944, in New York, N. Y., during the 1944 Annual Meeting of the Society. There have been no other meetings of the committee or its subcommittees during the year because of the difficulties encountered due to war conditions.

These same wartime conditions have retarded much of the research and other activities that often have yielded information warranting new recommendations affecting standards. Moreover, experiences with new products and processes and with masonry structures built during the war have not been reported with sufficient completeness to warrant analysis and conclusions, and the nature and extent of revisions that may be suggested by these experiences cannot be foretold now. The committee and many of the subcommittees are planning for the future and the termination of the war undoubtedly will show renewed activity.

Revision of Tentative Specifications

Subsequent to publication in 1941, of the Tentative Specifications for Vitrified Clay Filter Block for Trickling Filters (C 159 – 41 T),[1] competent critics of the specifications suggested the desirability of including requirements limiting the size and shape of the drainage channels. It was pointed out that drainage channels of a small cross-sectional area might not have sufficient capacity and that those of rectangular cross-section would clog more rapidly than those narrower at the base than at the top. The committee accordingly recommends[2] the following revision in these specifications which it is believed will provide the desired limits on size and shape of drainage channels:

New Section.—Add a new Section 8 to read as follows, renumbering the subsequent sections accordingly:

> 8. *Drainage Channels.*—(*a*) The aggregate effective cross-sectional area of the drainage channels in a filter block shall not be less than 15 sq. in. per ft. of width of that filter block. The effective cross-sectional drainage area shall be defined and measured as the sectional area lying below the lowest level of the aperture slots.
>
> (*b*) The cross-sectional shape of the bottom of the drainage channels of any filter block shall be curved or narrowed in width to form a trough in the bottom of each channel, so as to accelerate flow of effluent and to minimize stranding of solids in such channels.
>
> (*c*) The height of the drainage channels in any filter block shall be not less than 2½ in. measured from the lowest level of the aperture slots.
>
> (*d*) There shall be not less than two parallel drainage channels per foot of width of a type I filter block.

This recommendation has been submitted to letter ballot of the committee which consists of 52 members; 29 members returned their ballots, of whom 23 have voted affirmatively, 0 negatively, and 6 members marked their ballots "not voting."

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 Book of A.S.T.M. Standards, Part II.

[2] See Editorial Note, p. 215.

ACTIVITIES OF SUBCOMMITTEES

Most of the subcommittees are faced with several problems relating to standards under their jurisdiction. The subcommittees concerned with masonry units used in building construction are following the rapid progress being made by industry and the Sectional Committee on Coordination of Dimensions of Building Materials and Equipment (A.S.A. Project A62) in the development of workable plans for the coordination of dimensions of building materials. Some of the members of Committee C-15 are active in this work and are keeping the committee informed regarding actions in which it may be interested.

This report has been submitted to letter ballot of the committee which consists of 52 members; 29 members returned their ballots, of whom 28 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

D. E. PARSONS,
Chairman.

J. W. WHITTEMORE,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-15 recommended to the Administrative Committee on Standards that the Tentative Specifications for Vitrified Clay Filter Block for Trickling Filters (C 159 - 41 T) be revised as covered in the report. This recommendation was accepted by the Standards Committee on July 24, 1945, and the revised specifications appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part II, bearing the designation C 159 - 45 T.

REPORT OF COMMITTEE C-16

ON

THERMAL INSULATING MATERIALS*

Committee C-16 on Thermal Insulating Materials held no meeting during the past year. However, several subcommittees held meetings in Pittsburgh, Pa., during the week of February 26, 1945. There have been several changes in the membership of the committee.

The committee records with sorrow the death of Commander F. C. Houghten, chairman of the Joint Committee on Thermal Conductivity of All Forms of Insulation. This was a serious loss to the committee as Commander Houghten had served the committee faithfully and well. The Advisory Committee took appropriate action and sent a copy of the resolution to the late Commander's family.

I. ADOPTION OF TENTATIVE METHODS AS STANDARD

The committee recommends that the following three tentative methods be approved for reference to letter ballot of the Society for adoption as standard with revisions in two as indicated:

Method of Test for Compressive Strength of Preformed Block Type Thermal Insulation—Identical with the test in Tentative Method C 165 - 41 T.[1]

Tentative Methods of Test for Covering Capacity and Volume Change Upon Drying of Thermal Insulating Cement (C 166 - 41 T)[1] with the last sentence in Section 5 (*f*), changed to read as follows: "The oven chamber shall be adequately vented in such manner as to ensure complete circulation of the atmosphere of the entire oven chamber, preferably by fan or other forced circulation method."

Tentative Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (C 177 - 42 T)[1] with the following revisions:

Section 4 (*b*).—Change the third sentence to read: "The term guarded hot plate is applied to the entire assembled apparatus including the heating unit, the cooling units and the edge insulation."

Add the following note at the end of Paragraph 4 (*b*):

NOTE.—The surfaces of the heater plates and cooling plates should be finished to as nearly a true plane as possible and should be checked periodically. Variations over 90 per cent of the surface should be nil with maximum variations on any portion of the surface not exceeding 0.003 to 0.005 in.

Add a new Paragraph 4 (*g*) to read as follows, relettering the present Paragraph (*g*) as (*h*):

(*g*) The edge insulation may be of any convenient loose fill or blanket type insulating material to reduce edge losses from the heater plate, test specimens and cooling plates. It shall be of such thickness that the resistance to edge losses shall be at least twice and preferably three or more times the thermal resistance of the specimen in the direction of normal heat flow.

II. TENTATIVE METHOD CONTINUED AS TENTATIVE

The committee recommends that the test for flexural strength now appearing in the Tentative Methods of Test for Compressive Strength and Flexural Strength of Preformed Block Type Thermal Insulating Materials (C 165 - 41 T)[1] be continued as tentative without revision and published separately under a new A.S.T.M. designation.

III. REVISION OF TENTATIVE SPECIFICATIONS

The committee recommends that the

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 Book of A.S.T.M. Standards, Part II.

Tentative Specifications for Mineral Wool Thermal Insulating Cement (C 195 – 44 T)[2] be revised as follows and continued as tentative:

Section 2.—Change the requirement for thermal conductivity at a mean temperature of 200 F. from "0.80" to read "0.70" max., Btu. in. per sq. ft. per hr. per deg. Fahr.

Section 4 (d).—Following the sentence reading "The perforated plate. . . ." add the following sentence: "The oven chamber shall be adequately vented in such a manner as to ensure complete circulation of the atmosphere of the entire oven chamber, preferably by fan or other forced circulation method."

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. Adoption of Tentative Methods as Standard			
Test for Compressive Strength of Preformed Block Type Thermal Insulation (Identical with test in Method C 165 – 41 T)	37.	0	6
Test for Covering Capacity and Volume Change Upon Drying of Thermal Insulating Cement (C 166 – 41 T), as revised	29	2	6
Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (C 177 – 42 T), as revised	39	0	4
II. Tentative Method Continued as Tentative			
Test for Flexural Strength of Preformed Block Type Thermal Insulation (Identical with test in Method C 165 – 41 T)	37	0	6
III. Revision of Tentative Specifications			
Spec. for Mineral Wool Thermal Insulating Cement (C 195 – 44 T)	36	1	7

In Paragraph 4 (*e*) add the same sentence as given above in Paragraph 4 (*d*), after the sentence which reads "The oven shall have a volume. . . ."

An editorial change is also recommended in Specifications C 193 – 44 T, C 194 – 44 T, C 196 – 44 T, and C 197 – 44 T, for thermal insulating cements comprising the inclusion in each of the sentence on circulation of air in the oven to read as given above in Section 5 (*f*) of Specifications C 166.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 51 members, with the results shown in Table I.

IV. Emergency Standards

The committee recommends that the following Emergency Standards be withdrawn:[2]

Emergency Specifications:

Blanket Thermal Insulation for Building Purposes (ES - 14),
Blanket Thermal Insulation for Industrial Purposes (ES - 15),
Blanket Thermal Insulation for Refrigeration Purposes (ES - 16),
Preformed Pipe Covering Thermal Insulation (ES - 17),
Preformed Block Thermal Insulation (ES - 18), and
Structural Insulating Board Thermal Insulation (ES - 19).

Activities of Subcommittees

Subcommittee I on Physical Properties of Preformed Block Insulation, Including Pipe Covering (C. B. Bradley, chairman).—This subcommittee is now giving further study to the test for flexural strength as applied to wool-type block insulation. A series of tests recently performed seems to indicate that some modification of this test may be advisable when applying it to blocks made from wool-type insulation or that a completely new form of test may have to be developed for testing this characteristic.

Subcommittee II on Physical Properties of Insulating Board Made from Both Mineral and Vegetable Materials (P. D. Close, chairman).—Study and revision of present test procedures applicable to insulating board are being undertaken by this subcommittee as a necessary preliminary to the writing of specifications.

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[2] See Editorial Note, p. 219.

Subcommittee III on Physical Properties of Thermal Insulating Cement (H. W. Greider, chairman).—A cooperative program of study of methods of testing the adhesiveness of thermal insulating cement to steel is under way. This program, which includes consideration of the Navy method, has for its objective the development of an improved test method.

Subcommittee IV on Physical Properties of Blanket and Semirigid Insulation Made from Both Mineral and Vegetable Materials (R. E. Cryor, chairman).—Two characteristics relating to blanket and semirigid types of insulation are at present under discussion. These are fire resistance and the effect of wetting. Test procedures are being outlined for these two items.

Subcommittee V on Physical Properties of Loose-Fill Thermal Insulation Made from Both Mineral and Vegetable Materials (J. F. White, chairman).—Physical properties for which tests should be made have been established and test procedures are being formulated. Use specifications that will include both mineral and vegetable loose-fill with appropriate temperature limits are being prepared.

Subcommittee VI, the A.S.T.M. Group of the Joint Committee on Measurement of Thermal Conductivity of All Forms of Insulation (F. B. Rowley, chairman).—This group has under consideration two problems, first the guarded hot box method for measuring heat transmitted through a structure, such as a wall or a ceiling, and second the test procedure for the measurement of thermal conductivity of sectional pipe covering.

Subcommittee VII on Measurement of Thermal Properties Other Than Thermal Conductivity of Thermal Insulating Materials (G. M. Rapp, chairman).—The work of this subcommittee includes consideration of test procedures to measure the following characteristics: Determination of the maximum temperature at which a material remains stable, and change of volume upon increase in temperature. These are to be studied with particular reference to preformed block types of heat insulation.

Subcommittee VIII on Studies of Dimensional Standards of Preformed Block Insulation (Ray Thomas, chairman).—Discussion of the proposed revision of dimensional standards is being continued in this subcommittee.

Subcommittee IX, the A.S.T.M. Group of the Joint Committee on Studies of Vapor Barriers Applied to Thermal Insulation Used Especially in the Air Conditioning and Refrigeration Fields (R. H. Heilman, chairman).—This work has expanded to the point that the steering subgroup of this joint committee thought it advisable to invite the cooperation of other associations. Invitations to be represented on the joint committee have been sent to the Technical Association of the Pulp and Paper Industry, Insulation Board Institute, Committee on Condensation Control, National Door Manufacturers Association, and National Housing Authority. By bringing into this work representatives of other groups that have vital interest in the subject of vapor barriers, it was felt that the promiscuous formulation of units of measure and methods of test for vapor control would be discouraged and that more rapid progress would be made leading to standardized procedures.

The preliminary work of abstracting the published articles on vapor barriers has been completed and the report, printed under the auspices of the Office of Production, Research, and Development of the War Production Board, will soon be ready for restricted distribution.

The next step in the program of the joint committee is to select two test procedures for the determination of rate of vapor migration through barriers and to conduct tests on representative materials used as barriers. Efforts will be made to have this work financed by O.P.R.D.

This report has been submitted to letter ballot of the committee, which consists of 51 members; 47 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

E. T. COPE,
Chairman.

RAY THOMAS,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 7, a proposed revision of the Tentative Specifications for Mineral Wool Thermal Insulating Cement (C 195 - 44 T) as covered in the report was submitted by Committee C-16 and accepted by the Administrative Committee on Standards on June 27, 1945. The revised tentative appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part II, bearing the designation C 195 - 45 T.

At the same time, the Standards Committee accepted the recommendation of Committee C-16 that the following Emergency Standards be withdrawn:

Emergency Specifications for:

Blanket Thermal Insulation for Building Purposes (ES - 14),
Blanket Thermal Insulation for Industrial Purposes (ES - 15),
Blanket Thermal Insulation for Refrigeration Purposes (ES - 16),
Preformed Pipe Covering Thermal Insulation (ES - 17),
Preformed Block Thermal Insulation (ES - 18), and
Structural Insulating Board (Thermal Insulation) (ES - 19).

REPORT OF COMMITTEE D-1

ON

PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS[*]

Committee D-1 on Paint, Varnish, Lacquer, and Related Products held one meeting during the year: on June 28, 1944, in New York, N. Y., during the Annual Meeting of the Society.

During the past year Subcommittee XVIII on Physical Properties of Materials has been divided into two subcommittees: Subcommittee X on Optical Properties (M. Rea Paul, chairman) and Subcommittee XVIII on Physical Properties of Materials (R. H. Sawyer, chairman). Subcommittee X will investigate and develop instrumental methods of test for optical properties of protective coatings. Subcommittee XVIII will investigate and develop methods of test for the physical properties of protective coatings.

R. D. Bonney, H. A. Nelson, and C. H. Rose have been appointed to serve as representatives of the Society on a Joint Committee on Paint, Varnish, and Lacquer, which has been organized in conjunction with the Federation of Paint and Varnish Production Clubs as a conference committee.

Subsequent to the 1944 Annual Meeting, Committee D-1 presented to the Society through Committee E-10 on Standards proposed Tentative Specifications for Wood to be Used as Panels in Weathering Tests of Paints and Varnishes, to supersede Standard Specifications D 358 – 38, and a proposed tentative revision of the Standard Specifications for Zinc Sulfide Pigments (D 477 – 41). These recommendation were accepted[1] by Committee E-10 on August 28, 1944, and the new tentative specifications, bearing the designation D 358 – 44 T, and the tentative revision appear in the 1944 Book of A.S.T.M. Standards, Part II.

On September 27, 1944, the Standards Committee accepted the recommendation of Committee D-1 that the Emergency Method for Conducting Salt Spray Tests on Organic Protective Coatings (ES – 3) be withdrawn.

New Tentative Methods of Sampling and Testing Turpentine (D 233 – 44 T) were accepted[1] by Committee E-10 on October 30, 1944, to supersede Standard Methods D 233, as recommended by Committee D-1. These revised methods had also been approved by letter ballot of Committee D-17 on Naval Stores. The new tentative methods appear in the 1944 Book of A.S.T.M. Standards, Part II.

RECOMMENDATIONS AFFECTING STANDARDS

Fourteen subcommittees have submitted reports of progress, nine of which cover recommendations affecting standards as a result of which the committee is submitting three new tentative methods, revisions of two tentative methods, revisions of three standards for immedi-

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[*] Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-1 reported the following results of the letter ballot vote from a committee membership of 237: D 358, affirmative 82, negative 1, ballots marked "not voting" 35; D 477, affirmative 78, negative 1, ballots marked "not voting" 39; D 233, affirmative 89, negative 1, ballots marked "not voting" 26.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. New Tentatives			
Test for Evaluating Degree of Resistance of Traffic Paints to Abrasion	99	0	50
Methods for Producing Films of Uniform Thickness of Organic Finishing Materials on Test Panels	98	0	51
Recommended Practice for Operating Light and Water Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer and Related Products	96	0	53
II. Revision of Tentative Methods			
Test for Phthalic Anhydride Content of Alkyd Resin Solutions (D 563 – 43 T)	92	0	57
Method for Preparation of Steel Panels for Exposure Tests of Enamels for Exterior Service (D 609 – 41 T)	105	2	42
III. Revisions of Standards, Immediate Adoption			
Spec. for Butanol (Normal Butyl Alcohol) (D 304 – 40)	80	0	69
Test for Coarse Particles in Pigments, Pastes, and Paints (D 185 – 37)	100	0	49
IV. Tentative Revisions of Standards			
Spec. for Pure Chrome Green (D 212 – 41)	96	0	53
Spec. for Chrome Oxide Green (D 263 – 41)	96	0	53
Spec. for Prussian Blue (D 261 – 41)	93	0	56
Spec. for Ultramarine Blue (D 262 – 41)	87	0	62
Spec. for Titanium Dioxide Pigments (D 476 – 41)	93	3	54
Spec. for Bone Black (D 210 – 41)	86	0	63
Spec. for Carbon Black (D 561 – 41)	88	0	61
Spec. for Lampblack (D 209 – 41)	89	1	59
Chemical Analysis of White Pigments (D 34 – 39)	93	0	56
Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 – 44)	101	0	48
V. Adoption of Tentatives as Standard			
Evaluating the Degree of Resistance to Blistering of Organic Coatings on Metal When Subjected to Immersion or Other Tests Involving Exposure to Moisture or Liquids (D 714 – 43 T)	97	0	52
Analysis of Barium Sulfate Pigments (D 715 – 43 T)	95	0	54
Analysis of Mica Pigment (D 716 – 43 T)	91	0	58
Analysis of Magnesium Silicate Pigment (D 717 – 43 T)	91	0	58
Analysis of Aluminum Silicate Pigment (D 718 – 43 T)	88	0	61
Analysis of Diatomaceous Silica Pigment (D 719 – 43 T)	89	0	60
VI. Adoption as Standard of Tentative Revision of Standard			
Spec. for Zinc Sulfide Pigments (D 477 – 41)	85	0	64
VII. Editorial Change in Standard			
Sampling and Testing Lacquer Solvents and Diluents (D 268 – 44)	91	0	58

ate adoption, revisions of ten standards for publication as tentative, and is recommending the adoption of six tentatives as standard without revision, and the adoption as standard of one tentative revision of a standard.[1a] The standards affected are listed in Table I and the recommendations are explained in the reports of the subcommittees directly responsible for them.

These recommendations have been submitted to letter ballot of the committee which consists of 239 voting members, with the results shown in Table I.

Activities of Subcommittees

Subcommittee II on Drying Oils (Francis Scofield, chairman) recommends that the Tentative Specifications for Oiticica Oil (Permanently Liquid) (D 601 – 41 T)[2] be continued as tentative without revision.

The subcommittee is preparing specifications for dehydrated castor oil and is developing a polymerization test for drying oils. Methods of testing bodied linseed oils are also being developed.

Subcommittee III on Bituminous Coatings (E. F. Hickson, chairman) is preparing specifications and methods of test for asphalt base and coal-tar base emulsions.

Subcommittee IV on Traffic Paints (Anthony Skett, chairman) recommends for publication as tentative a new Method of Evaluating Degree of Resistance of Traffic Paint to Abrasion, Erosion, or a Combination of Both, in Road Service Tests.[3]

[1a] See Editorial Note, p. 227.

[2] 1944 Book of A.S.T.M. Standards, Part II.

The subcommittee also recommends that the following tentative methods be continued as tentative because of their limited use during the past two years: Tentative Methods of Test for Dry to No-Pick-Up Time of Traffic Paint (D 711 - 43 T), for Light Sensitivity of Traffic Paint (D 712 - 43 T), and for Conducting Road Service Tests on Traffic Paint (D 713 - 43 T).

Progress is being made by the subcommittee in its work on methods of test for evaluating traffic paints and it is expected that a proposed method of test for evaluating the degree of chipping of traffic paints will be submitted shortly.

Subcommittee V on Volatile Hydrocarbon Solvents for Organic Protective Coatings (E. M. Toby, Jr., chairman) is developing methods for determining the solvency, volatility of hydrocarbon solvents and solvent escape and solvent retention are also being studied. The subcommittee is reviewing the methods of test used for evaluating hydrocarbon solvents in the protective coatings industry.

Subcommittee VI on Definitions (C. H. Rose, chairman) is revising some of the current definitions and is preparing some new definitions for terms used in connection with protective coatings.

Subcommittee VII on Accelerated Tests for Protective Coatings (H. A. Nelson, chairman) has presented for publication a Tentative Recommended Practice for Operating Light and Water Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer and Related Products.[3]

The subcommittee recommends that the Tentative Method for Preparation of Steel Panels for Exposure Tests of Enamels for Exterior Service (D 609 - 41 T) be revised, including a change of title to read Tentative Method for the Preparation of Steel Panels for Testing Paint, Varnish, Lacquer, and Related Products.

It is recommended that the Tentative Method for Evaluating the Degree of Resistance to Blistering of Organic Coatings on Metal When Subjected to Immersion or Other Tests Involving Exposure to Moisture or Liquids (D 714 - 43 T) be adopted as standard without revision.

The subcommittee also recommends that the Emergency Method of Test for Changes in Protective Properties of Organic Coatings on Steel when Subjected to Immersion (ES - 35) be continued in its present form.

Work is under way looking toward the development of apparatus and methods for conducting humidity exposure tests for paints on metal as well as the development of a procedure for cleaning steel panels in preparation for painting.

The subcommittee is planning to conduct work on methods for alternate immersion and exposure tests and procedures for field testing of paint on metal.

Subcommittee VIII on Methods of Analysis (E. F. Hickson, chairman) recommends the following revision for immediate adoption in the Standard Methods of Test for Coarse Particles in Pigments, Pastes and Paints (D 185 - 37),[2] and the committee accordingly asks for a nine-tenths vote at the Annual Meeting in order that this modification may be referred to letter ballot of the Society:

New Section.—Add a new Section 5 to

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[3] This method was accepted as tentative by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part II.

[4] This revised method was accepted by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part II.

read as follows, renumbering the subsequent sections accordingly:

5. (*a*) Make a stock solution of dispersing agent (Note) in water using as high a concentration of dispersing agent as possible without losing fluidity. When solution has been obtained, filter through coarse filter paper. A quart of this solution will be sufficient for several tests.

NOTE.—Triton 720, Darvan No. 1, or any other dispersing agent specific for carbon black may be used.

(*b*) Crush the pellets between two approximately 12 by 12-in. glass plates using a gentle rotating motion. If 10 g. of carbon black are taken, crush about 2 g. at a time. Weigh into a 600-ml. beaker 10 g. of the crushed particles. Add enough of the dispersing solution to make a heavy paste and mix well to incorporate thoroughly the carbon black. Dilute with water to about 300 ml. then pour into a clean No. 325-sieve. The tap water used throughout shall first be passed through the No. 325-sieve. Using a small camels hair brush gently brush the mix through the sieve, running tap water slowly through at the same time. When it appears that all the dispersed black has gone through, stop the tap water and continue brushing until most of the water remaining on the sieve has gone through. Add a few milliliters of the stock dispersing agent solution, thoroughly mix with the brush, then turn on the tap water again and wash through as before. Repeat this operation until no dispersed black comes through the sieve. When about 0.5 g. of sand-like material is left on the screen the end point is being approached. At this point adding the dispersing solution and gently rubbing it into the residue with the finger still produces a colloidal dispersion of black which easily passes through the sieve. From this point on, before each addition of dispersing agent, work the residue into the center of the sieve with the tap water. It takes many washings and many additions of dispersing solution to reach the end point and the operator is cautioned not to be misled into thinking all the black has been washed through before it is an accomplished fact.

(*c*) Dry the sieve in an oven at 105 to 110 C. for 1 hr., cool, weigh the residue, and calculate the percentage of coarse particles. If the value thus obtained is greater than that specified, proceed as follows to remove any adhered carbon which will pass through the No. 325-sieve: Transfer the particles on the sieve to a piece of white bond paper and gently rub the carbon onto the paper with the finger. When no further real blackening of the paper occurs carefully transfer the residue to the balance pan, weigh and recalculate the percentage of coarse particles.

This revision will make the method applicable to carbon black in pellet form which is covered by the proposed revision in the Standard Specifications for Carbon Black (D 561 - 41) recommended by Subcommittee XV.

The subcommittee recommends for publication as tentative the following revision of the Standard Methods of Chemical Analysis of White Pigments (D 34 - 39):[2]

Section 34.—Change the seventh sentence to read as follows by the addition of the italicized words and figures:

Wash out a Jones reductor,[14] *having a zinc column of at least 45 cm. in length and 1.9 cm. in diameter* with diluted H_2SO_4 (1:19) and water, leaving sufficient water in the reductor to fill to the upper level of the zinc.

Change footnote 14 to read as follows:

[14] Directions for preparing a Jones reductor may be found in Hillebrand and G. E. F. Lundell, "Applied Inorganic Analysis" (1929), p. 100.

The subcommittee recommends for publication as tentative the following revision of the Standard Method of Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 - 44):[2]

Section 4.—Change the first three sentences to read as follows by the addition of the italicized words and the omission of those in brackets:

Thoroughly mix the sample of paint and strain it into [the] *a* 1-pt. container [and allow the paint to stand over 12 to 24 hr.]. Bring the temperature of the sample to 25 ± 0.25 C. and maintain it at that temperature during the test. *Allow a minimum of 1 hr. to elapse between the time the paint is strained and the test is begun. Stir the paint carefully, to avoid entrapping air, and then* place the container on the platform of the viscosimeter so that the paddle-type rotor is immersed in the sample just to the mark on the shaft of the rotor.

It is recommended that the following tentative methods be adopted as standard without change:

Tentative Methods of:[2]

Analysis of Barium Sulfate Pigments (D 715 – 43 T),
Analysis of Mica Pigment (D 716 – 43 T),
Analysis of Magnesium Silicate Pigment (D 717 – 43 T),
Analysis of Aluminum Silicate Pigment (D 718 – 43 T), and
Analysis of Diatomaceous Silica Pigment (D 719 – 43 T).

Subcommittee IX on Varnish (W. T. Pearce, acting chairman) recommends that the Tentative Method of Test for Phthalic Anhydride Content of Alkyd Resin Solutions (D 563 – 43 T) be revised as appended hereto.[4] This revised method requires less time and simpler apparatus for determining the phthalic anhydride in alkyd resin.

The subcommittee is studying methods for the more accurate measurement of drying of protective coatings and is studying methods of tests used for resins such as melting point, total solids, and color.

Subcommittee X on Optical Properties (M. Rea Paul, chairman) is studying methods of test for color, specifications and methods of test for gloss, color differences, infra red reflectance, and other optical properties.

Subcommittee XIII on Shellac (W. H. Gardner, chairman) recommends that the Tentative Method of Test for Color of Orange Shellac (D 29 – 41 T) and the Tentative Specifications for Orange Shellac and Other Lacs (D 237 – 43 T) be continued as tentative because consideration is being given to recommending certain changes in these methods and specifications.

Subcommittee XV on Specifications for Pigments, Dry and in Oil, When Marketed in That Form (C. L. Crockett, chairman) recommends the following tentative revisions in eight standard specifications for pigments to bring them up to date so that they will more adequately cover the products now on the market and in some instances to permit a small percentage of surface treating agents in addition to the specified composition of the pigment:

Standard Specifications for Pure Chrome Green (D 212 – 41):[2]

Section 2 (a).—Change to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

2. (*a*) Dry Pigment.—The pigment shall be a precipitated mixture of lead chromate and iron *blue* (*potassium or ammonium ferriferrocyanide*) [ferrocyanide and ferricyanide blue] with or without other insoluble compounds of lead [and]. *It shall be free from admixture of any substances other than those added during manufacture in small amounts up to a total of 7 per cent to improve the stability and/or working properties of the pigment. However, extender pigments such as barium sulfate, silica, silicates, calcium carbonate, calcium sulfate, magnesium carbonate, etc., shall be absent. It* shall conform to the following requirements:

Of the total lead[a] in the pigment, percentage present as chromate ($PbCrO_4$), min.	70
Moisture and other volatile matter, max., per cent	4.0
[Total other impurities, max., per cent	3.0]
Total matter soluble in water, max., per cent	*1.0*
Organic colors or lakes	*none*
Coarse particles (total residue retained on a No. 325 (44-micron) sieve, max., per cent	1.0

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[a] Calculated as metallic lead.

Standard Specifications for Chrome Oxide Green (D 263 – 41):[2]

Section 2 (a).—Add the following requirements:

Total matter soluble in water, max., per cent	0.5
Organic colors or lakes	none

Standard Specifications for Prussian Blue (D 261 – 41):[2]

Change the title to read "Tentative Specifications for Iron Blue," and indicate in Section 1 on Scope that the specifications also cover Milori blue.

Section 2 (a).—Change to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

> 2. (*a*) Dry Pigment.—The pigment shall be the blue product formed by the reaction of *a* solution[s] of iron salts with *a ferro-* [ferrocyanide] or ferricyanide solution. It shall *be free from admixture of any substances other than those added during manufacture, in small amounts up to a total of 4 per cent, for the purpose of improving the quality and/or working properties of the pigment* [not be admixed with any other substance]. *However, extenders and diluents such as barium sulfate, silica, silicates, calcium carbonate, calcium sulfate, magnesium carbonate, etc. shall be absent.* The pigment shall conform to the following requirements:

Total matter soluble in water, max., per cent	*1.0* [0.5]
Moisture and other volatile matter, max., per cent	7.0
Organic colors or lakes	*none*

> *The acidity or alkalinity of the aqueous extract, with methyl orange indicator, shall not exceed the chemical equivalent of 0.1 per cent of sulfuric acid, calculated on the dry pigment.*

Standard Specifications for Ultramarine Blue (D 262 – 41):[2]

Section 2.—Change Paragraph (*a*) from its present form: namely,

> 2. (*a*) *Dry Pigment.*—The pigments shall be manufactured ultramarine blue obtained by the furnacing of mixtures of clays and silicas with sodium salts, sulfur, and carbonaceous material, and having a chemical composition which will generally fall within the following range, expressing the elements except sulfur as their oxides:

Sodium oxide, per cent	18 to 23
Aluminum oxide, per cent	20 to 32
Silicon dioxide, per cent	35 to 50
Sulfur, per cent	8 to 14

> The pigment shall conform to the following requirements (Note):

Moisture and other volatile matter, max., per cent	4.0
Coarse particles (total residue retained on a No. 325 (44-micron) sieve), max., per cent	1.0

to read as follows:

> 2. (*a*) *Dry Pigment.*—The pigment shall be a manufactured product obtained by the calcining of mixtures of clays and silicas with sodium salts, sulfur, and carbonaceous material. It shall be a soft, dry, finely ground powder of good blue color, free from admixtures of color substances, and shall conform to the following requirements:

Coarse particles (residue retained on a No. 325 (44-micron) sieve), max., per cent	1.0
Moisture and other volatile matter, max., per cent	4.0
Matter soluble in water, max., per cent	1.5
Organic colors or lakes	none

Omit footnote 3.

Delete the note following Paragraph (*d*) and the references to it in Paragraphs (*b*) and (*c*).

Standard Specifications for Titanium Dioxide Pigments (D 476 – 41):[2]

Section 1.—Change the description of titanium dioxide from "commercially pure," to read "unextended, including anatase and rutile crystal type pigments."

Section 2.—Replace Paragraph (*a*) which refers to Table I with the following Paragraphs (*a*) and (*b*), and reletter the present Paragraph (*b*) as (*c*):

> 2. (*a*) The titanium dioxide pigment shall conform to the requirements for composition prescribed in Table I. It shall be a chemically precipitated pigment consisting of anatase or rutile titanium dioxide with or without admixtures of other insoluble oxides of antimony, zinc, aluminum, etc., or other treating agents, but without other admixtures except those of reagent materials introduced specifically to improve those properties for which the pigment is used. The unextended titanium dioxide pigment shall be free of extenders such as barium, sulfate, clay, magnesium silicate, whiting, etc.
>
> (*b*) Titanium-barium pigment, titanium-calcium pigment, and titanium-magnesium pigment

shall conform to the requirements for composition prescribed in Table I.

Table I.—Change the requirements for titanium dioxide in titanium dioxide pigment from "97.0" to read "94.0" min., per cent, and delete the requirements for class B titanium barium pigment.

Standard Specifications for Bone Black (D 210 - 41):[2]

Section 2 (a).—Change the requirement for ash insoluble in acids from "1.0" to read "3.0" max., per cent, and delete the requirement reading "Tone when diluted with zinc oxide . . . clear blue gray."

Standard Specifications for Carbon Black (D 561 - 41):[2]

Section 2 (a).—Change to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

2. (*a*) The pigment shall be made by burning natural gas in such a manner as to form a deposit of carbon [but without any admixtures]. *It shall be free from adulterants and be in the form of "powder" or "pellets" (dustless)*, and shall conform to the following requirements:

Ash, max. per cent	0.2[a]
Acetone extract, max., per cent	0.5[a]
Coarse particles [True grit (total residue)] retained on a No. 325 (44-micron) sieve, max., per cent	0.2[b]
Moisture (*loss at 105 C.*) [and other volatile matter], max., per cent	8.0[c]
Organic dyes	*none*

[a] *Higher maximum ash and acetone extract values may be allowed when mutually agreed upon by the purchaser and the seller, if final product requirements necessitate the use of additional treating agents.*

[b] *Coarse particle determination should be made on "pellet" type black by special method for carbon black in this form.*

[c] It may be necessary for the purchaser and the seller to agree upon a higher maximum moisture content in high-color blacks.

Standard Specifications for Lampblack (D 209 - 41):[2]

Section 2 (a).—Add the following requirement to the table at the end of this section:

Moisture and other volatile matter, max., per cent	3.0

The subcommittee recommends that the tentative revision[2] of the Standard Specifications for Zinc Sulfide Pigments (D 477 - 41) be adopted as standard.

The Tentative Specifications for Red and Brown Iron Oxide Pigments (D 84 - 43 T) are recommended for continuation as tentative without revision.

The subcommittee also recommends that the Emergency Alternate Provision applying to the Standard Specifications for Mica Pigment (D 607 - 42) be continued.[1a]

The subcommittee is writing specifications for pumice for use in traffic paint and specifications for iron oxide pigment pastes.

Subcommittee XVIII on Physical Properties (R. H. Sawyer, chairman) recommends for publication as tentative Methods for Producing Films of Uniform Thickness of Organic Finishing Materials on Test Panels.[3]

The subcommittee is developing methods for the measurement of film thickness, adhesion, and abrasion-resistance of protective coatings.

Subcommittee XXV on Cellulosic Coatings and Related Materials (R. M. Carter, chairman) recommends the following editorial revision in the Standard Methods of Sampling and Testing Lacquer Solvents and Diluents (D 268 - 44):

Section 21.—Change "porcelain evaporation dish" to read "flat dish of Petri type."

The subcommittee recommends for immediate adoption the following revision in the Standard Specifications for Butanol (Normal Butyl Alcohol) (D 304 - 40):

Section 2.—Change the distillation requirements from their present form, namely:

Distillation range:

Below 100 C.	none
Below 105 C.	not more than 2 per cent
Below 115 C.	not more than 10 per cent
Above 118 C.	none

to read as follows:

Distillation range:

Below 115 C.	none
Above 118.5 C.	none

The subcommittee recommends that Tentative Specifications for Methyl Ethyl Ketone (D 740 - 43 T)[2] be continued as tentative because the subcommittee has under consideration certain revisions in these specifications.

Consideration is being given to revising the Specifications for Tricresyl Phosphate (D 363 - 36). The present boiling range requirements in the specifications for solvents and diluents are being reviewed to determine the changes which may be necessary as the result of the adoption of the recently established A.S.T.M. solvents distillation thermometers.

The subcommittee is also considering the resin and lacquer emulsions looking toward the establishment of a new working group, and is developing new methods of test for lacquer solvents and diluents and for ethyl cellulose and cellulose acetate.

Subcommittee XXIX on Painting of Structural Iron and Steel (A. J. Eickhoff, chairman) has underway a testing program to study the effects of chemical treatment prior to repainting steel which had originally been given a chemical treatment prior to the original paint job.

This report has been submitted to letter ballot of the committee, which consists of 239 voting members; 149 members returned their ballots, of whom 100 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

W. T. PEARCE,
Chairman.

C. H. ROSE,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-1 presented to the Society through the Administrative Committee on Standards the recommendations affecting tentatives and the tentative revision of standards listed in the Summary of Proceedings, p. 7, and referred to in the report. These recommendations were accepted by the Standards Committee on August 27, 1945, and the new and revised tentatives and the tentative revisions appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part II.

At the same time, the Society accepted the recommendation of the committee that Emergency Alternate Provisions EA - D 607 applying to the Standard Specifications for Mica Pigment (D 607 - 42) be continued in their present form.

REPORT OF COMMITTEE D-2

ON

PETROLEUM PRODUCTS AND LUBRICANTS*

Committee D-2 on Petroleum Products and Lubricants held two regular meetings during the past year (in June, 1944, in New York, N. Y., and in January, 1945, in Detroit, Mich.). The regular Spring Meeting planned to be held in March, 1945, in Chicago, Ill., was canceled because of wartime restrictions on meetings.

CHANGES IN COMMITTEE ORGANIZATION

During the year subcommittee and technical committee changes were effectuated as follows: Subcommittee IV on Grease (F. E. Rosenstiehl, acting chairman), was discharged, and its work turned over to a new Technical Committee G on Lubricating Greases.

Technical Committee B on Lubricants (H. C. Mougey, chairman) was reorganized as Technical Committee B on Lubricating Oils (T. C. Smith, chairman and J. C. Geniesse, secretary) with an Executive Committee and twelve sections as follows: Utility Sections on Automotive Engine Oil (W. A. Gruse, chairman); Aircraft Engine Oil (D. P. Barnard, chairman); Gear Oils (A. O. Willey, chairman); Hydraulic Oils (F. L. Miller, chairman); Instrument Oils (E. H. Erck, chairman); Lubricants for Air Compressors and Compressed Air Tools (C. M. Larson, chairman); Wire Rope Lubricants (E. Wilhofer, chairman); Quality Sections on Physical and Chemical Changes (L. L. Davis, chairman); Oxidation and Bearing Corrosion (H. R. Wolf, chairman); Foaming (H. A. Ambrose, chairman); General Sections on Standardization and Editorial (A. E. Becker, chairman); and Nomenclature (A. E. Flowers, chairman).

Technical Committee G on Lubricating Grease (F. L. Wright, chairman, C. W. Georgi, vice-chairman, and H. A. McConville, secretary) was organized with the formation of an Executive Committee and three Sections as follows: Section I on Chemical and General Laboratory Tests for Lubricating Greases (G. Kaufman, chairman), Section II on Consistency Measurements and Related Physical Tests for Lubricating Greases (C. W. Georgi, chairman), and Section III on Functional Tests for Lubricating Greases Employing Antifriction Bearings (T. G. Roehner, chairman).

TABLE I.

Title	A.S.T.M. Designation	ASA Number
NEW AMERICAN STANDARDS		
Test for Oil Content of Paraffin Wax	D 721 - 44	Z11.52—1944
Test for Knock Characteristics of Motor Fuels	D 357 - 44	Z11.37—1944
Test for Saponification Number of Petroleum Products by Color-Indicator Titration	D 94 - 44	Z11.20—1944
Method for Conversion of Kinematic Viscosity to Saybolt Furol Viscosity	D 666 - 44	Z11.53—1944
REVISION OF AMERICAN STANDARDS		
Test for Gum Content of Gasoline	D 381 - 44	Z11.36—1944
Test for Sulfur in Petroleum Oils by Bomb Method	D 129 - 44	Z11.13—1944
Test for Viscosity by Means of the Saybolt Viscosimeter	D 88 - 44	Z11.2—1944

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

Changes in Status of American Standards

Table I shows the changes in status during the year of American Standards for petroleum products, approved by the American Standards Association on the recommendation of Sectional Committee Z11 on Petroleum Products and Lubricants.

Activities of Technical Committee and Subcommittees

Technical Committee A on Gasoline (C. B. Veal, chairman) has submitted proposed revisions to Sections A5 (*f*) and A10 of the Standard Method of Test for Knock Characteristics of Motor Fuels (D 357 – 44) and Section A10 of the Tentative Method of Test for Knock Characteristics of Aviation Fuels (D 614 – 44 T) which are published as information in the report of this technical committee appended hereto.

Subcommittee X on Insoluble Content of Used Oils (L. L. Davis, chairman) developed the Emergency Method of Test for Isopentane and Benzene Insolubles in Used Lubricating Oils (ES – 42)[1] which was accepted by Committee E-10 on August 28, 1944, and recommends that it be editorially revised as follows:

Section 9 (*a*).—Change the reference "Section 8 (*a*) to (*c*)" to read "Section 8 (*a*) and (*b*)."

Section 9 (*b*).—Change the reference "Section 8 (*c*)" to read "Section 8 (*b*)."

Section 9 (*c*).—Change "103 ± 3 C." to read "105 ± 3 C."

Subcommittee XI on Determination of Inorganic Elements in Lubricants (Raymond Haskell, chairman) developed the Emergency Method of Test for Sulfated Residue from Lubricating Oils (Air-Ignition Method) (ES – 43)[2] which was accepted by Committee E-10 on Standards on February 1, 1945.

Emergency Methods ES – 36 to ES – 39, incl., which as mentioned in last year's report were developed by this subcommittee, were on the recommendation of Committee D-2 accepted[3] by Committee E-10 on Standards for publication as tentative on October 3, 1944. The new tentative methods have been assigned the designations indicated below:[1]

Tentative Methods of:

Test for Chlorine in Lubricating Oils by Bomb Method (D 808 – 44 T),
Chemical Analysis for Phosphorus in Lubricating Oils (D 809 – 44 T),
Chemical Analysis for Lead, Copper, and Iron in Lubricating Oils (D 810 – 44 T), and
Chemical Analysis for Metals in Lubricating Oils (D 811 – 44 T).

Subcommittee XV on Sampling and Gaging (A. E. Flowers, chairman) recommended the publication of explanatory notes as formulated by The Institute of Petroleum with the next publication of weight conversion tables such as those contained in Appendix I of the 1944 Report of Committee D-2.[4]

Subcommittee XVI on Cloud and Pour Test (L. C. Beard, Jr., chairman) prepared the comprehensive report on and a Proposed Method for Estimating Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants, which are appended to this report.[5]

Due to needs arising from the war for expediting a determination of very low pour points, the subcommittee prepared Emergency Alternate Provisions applying to the Standard Method of Test for Cloud and Pour Points (D 97 – 39) which were accepted by Committee E-10 on August 28, 1944, and published under the designation EA – D 97.[1,6]

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[1] 1944 Book of A.S.T.M. Standards, Part III.

[2] 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[3] In submitting these recommendations to Committee E-10 on Standards, Committee D-2 reported the following results of the letter ballot vote from a committee membership of 73: D 808 and D 811, affirmative 48, negative 0, ballots marked "not voting" 6; D 809 and D 810, affirmative 47, negative 0, ballots marked "not voting" 7.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 44 (1944).

[5] See pp. 237 and 244.

Subcommittee XXV on Analysis of Petroleum Products for Hydrocarbon Types (S. S. Kurtz, Jr., chairman) developed a Proposed Method for the Determination of Total Olefinic and Aromatic Hydrocarbons in Gasoline, which is presented as information in Appendix II.

The Emergency Method of Test for Olefins, Aromatics, Paraffins, and Naphthenes in Aviation Gasoline (Without Distillation into Fractions) (ES - 45) and the Emergency Method of Test for Benzene, Toluene, and Higher-Boiling Aromatics in Aviation Gasoline (ES - 46) have been released from the restricted list and are published in the 1944 Book of A.S.T.M. Standards, Part III.

EMERGENCY ALTERNATE PROVISIONS

In accordance with the recommendation of Subcommittee XIX on Illuminating Oils (L. C. Beard, Jr., chairman), the following alternate provisions applying to the apparatus and procedure in the Standard Method of Test for Burning Quality of Kerosine Oils (D 187 - 39)[1] are recommended for publication under the emergency procedure:[6]

> If it is found impossible to secure a Miller No. 2 Sun Hinge Burner or any other burner conforming to the requirements prescribed in Table I, then it will be permissible to use a Plume & Atwood No. 2349 No. 2 Sun Hinge Burner, waiving the requirements in Table I.
>
> If a Plume & Atwood Burner is used, the flame width in Section 4 (*a*) shall be $1\frac{1}{2}$ in. at its widest point instead of $1\frac{3}{4}$ in. as specified in the method. Since a somewhat smaller flame width is used, oil consumption will be decreased and hence Section 4 (*b*) under procedure shall permit a consumption of 41 ± 2 ml. instead of 43 ± 2 ml. as specified in the method.

I. NEW TENTATIVE METHOD

The committee recommends that the Method of Analysis of Petroleum Sulfonates,[7] as prepared by Subcommittee XXIV on Petroleum Sulfonates (V. F. Beyer, chairman) and substantially as published as information in the 1944 report of the committee,[4] be accepted for publication as tentative.

II. REVISION OF TENTATIVE METHOD

The committee recommends that the Tentative Method of Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter (**D 155 - 39 T**) be revised, as recommended by Subcommittee VI on Color (H. M. Hancock, chairman), by the deletion of the first sentence in Section 2 (*a*) which reads: "The A.S.T.M. Union Colorimeter shall bear a metal name plate marked with the following description and a serial number: A.S.T.M. Union Colorimeter, Licensed under U. S. Patent No. 1,495,763." This change is recommended because of the expiration of Patent No. 1,495,763.

III. REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revision in six standard methods of test, as set forth below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Method of Test for Carbonizable Substances in Paraffin Wax (**D 612 - 43**)[1] *and Method of Test for Carbonizable Substances in White Mineral Oil* (*Liquid Petrolatum*) (**D 565 - 43**).[1]—Subcommittee I on Pharmaceutical Tests (V. F. Beyer, chairman), has recommended clarification of the procedure set forth in the first sentence of Section 3 (*a*) of each of these methods by changing "diphenylamine solution (1 per cent)" to read "diphenylamine solution (1 g. diphenylamine in 100 ml. of concentrated sulfuric acid)."

Method of Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products (**D 86 - 40**).[1]—Subcommittee VIII on Distillation (E. W.

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[6] See Editorial Note, p. 232.

[7] This method was accepted as tentative by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

Dean, chairman) recommended that Note 3 in Section 3 (*d*) be changed from its present form: namely,

NOTE 3.—For products having end points not higher than 482 F. (250 C.) *or* initial boiling points not higher than 212 F. (100 C.), the Low-Distillation Thermometer shall be used; for products having end points higher than 482 F. (250 C.) *and* initial boiling points higher than 212 F. (100 C.) the High-Distillation Thermometer shall be used.

to read as follows:

NOTE 3.—Either the A.S.T.M. High- or Low-Distillation Thermometer shall be used depending upon the initial boiling point and the end point of the product. Use the A.S.T.M. Low-Distillation Thermometer for all materials except those found to have both the initial boiling points higher than 212 F. (100 C.) and final boiling points higher than 482 F. (250 C.) as determined using that thermometer.

Method of Test for Flash and Fire Points by Means of Open Cup (**D 92 – 33**).[1]—Subcommittee XII on Flash Point (C. F. Ramey, chairman) has recommended the following revisions:

Section 6.—Change from its present form: namely,

6. The flash point and fire point tests shall be made in a room or compartment free from air drafts. The operator shall avoid breathing over the surface of the oil. It is desirable that the room or compartment be darkened sufficiently so that the flash may be readily discernible.

to read as follows:

6. Laboratory conditions shall be such that flash and fire point tests are made in a room or compartment free from air currents. Care shall be observed to avoid disturbing the vapors evolved in the cup while heating, either by careless breathing or unnecessary movements near the flash cup. It is desirable that the room or compartment be darkened sufficiently so that the flash can be readily detected.

New Section.—Add a new Section 7 to read as follows:

7. Results shall not differ from each other by more than the following:

Repeatability	5 F.
Reproducibility	10 F.

Facilities referred to are of great importance and are enumerated in Section 6.

Method of Test for Saponification Number of Petroleum Products by Color-Indicator Titration (**D 94 – 44**).[1]—Subcommittee XIII on Neutralization Number and Saponification (H. P. Ferguson, chairman) has recommended the following revisions:

Section 8.—Change the next to the last sentence to read as follows by the addition of the italicized words:

Immediately disconnect the condenser, *cautiously* add 50 ml. of A.S.T.M. precipitation naphtha (Note 6), and titrate the solution while hot (*without reheating*) with 0.5 *N* HCl, using 3 drops of phenolphthalein indicator.

New Note.—Add a new Note 3, immediately following Note 2 in Section 5 (*b*), to read as follows, renumbering the subsequent Notes accordingly:

NOTE 3.—It has been found that 99 per cent isopropyl alcohol may be substituted for the purified ethanol and entirely satisfactory results obtained. This substitution is not permissible, however, in referee tests.

Method of Test for Knock Characteristics of Motor Fuels (**D 357 – 44**).[1]—The following revisions in the Appendix are recommended by Section IV on Detonation of Technical Committee A on Gasoline (D. B. Brooks, chairman):

Section A4 (*f*).—Change the parenthetical reference from "(See Note 2)" to read "(See Note 3)."

Section A8 (*d*).—Change the last sentence from "A felt washer is used on the exhaust valve stem only." to read "Felt washers are used on the valve stems."

Section A13 (*h*).—Delete the phrase "or a taper of 0.004 in."

IV. TENTATIVES CONTINUED AS TENTATIVE

It is recommended that the following, which have been published as tentative for two years or more without revision, be continued as tentative because revisions are under consideration or in prospect:

Tentative Specifications for:[1]

Fuel Oils (D 396 - 39 T),
Gasoline (D 439 - 40 T),

Tentative Methods of Test for:[1]

Sulfur in Petroleum Oils by Lamp Method (D 90 - 41 T),
Sediment in Fuel Oil by Extraction (D 473 - 38 T),
Ash Content of Petroleum Oils (D 482 - 43 T),
Oxidation Stability of Gasoline (D 525 - 42 T), and
Ignition Quality of Diesel Fuels (D 613 - 43 T).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 75 voting members, with the results shown in Table II.

Due to the retirement of R. P. Anderson on December 31, 1944, the committee recommended the appointment of D. V. Stroop as acting secretary and subsequently, by letter ballot, elected him to fill Dr. Anderson's unexpired term as secretary.

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE METHOD			
Analysis of Petroleum Sulfonates	46	1	15
II. REVISION OF TENTATIVE METHOD			
Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter (D 155 - 39 T)	57	0	5
III. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Test for Carbonizable Substances in Paraffin Wax (D 612 - 43)	46	0	16
Test for Carbonizable Substances in White Mineral Oil (Liquid Petrolatum) (D 565 - 43)	48	0	14
Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products (D 86 - 40)	57	0	5
Test for Flash and Fire Points by Means of Open Cup (D 92 - 33)	60	0	2
Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 - 44)	56	0	6
Test for Knock Characteristics of Motor Fuels (D 357 - 44)	48	0	14

This report has been submitted to letter ballot of the committee which consists of 75 voting members; 62 members returned their ballots, of whom 59 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

T. A. BOYD,
Chairman.

D. V. STROOP,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 8, two recommendations affecting tentatives and a proposed emergency alternate provision, which are also referred to in the report, were submitted by Committee D-2 and accepted by the Administrative Committee on Standards on June 27, 1945. The tentatives and the emergency provision appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

Subsequent to the Annual Meeting, Committee D-2 presented to the Administrative Committee on Standards the following recommendations:

Withdrawal of Emergency Alternate Provisions:

EA - D 97 applying to the Standard Method of Testing Cloud and Pour Points, and
EA - D 524 applying to the Standard Method of Testing Carbon Residue of Petroleum Products.

Reaffirmation of Emergency Standard:

ES - 32 applying to the Emergency Method of Testing Color of U. S. Army Motor Fuel (All Purpose) by Means of an A.S.T.M. Color Standard.

These recommendations were accepted by the Standards Committee on October 24, 1945.

On January 10, 1946, the Standards Committee accepted the recommendation of Committee D-2 that Emergency Standard ES - 43 applying to the Emergency Method of Test for Sulfated Residue from Lubricating Oils by Air-Ignition be revised. The revised emergency standard appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

REPORT OF TECHNICAL COMMITTEE A ON GASOLINE

PROPOSED REVISIONS IN THE METHODS OF TEST FOR KNOCK CHARACTERISTICS OF MOTOR FUELS (D 357 – 45) AND OF AVIATION FUELS (D 614 – 44 T)

This report presents the details of a proposed revision in the mixture heater assembly requirements in Section A5 (*f*) of the Standard Method of Test for Knock Characteristics of Motor Fuels (D 357 – 45) and in the exhaust system specifications in Section A10 of Method D 357 and the Tentative Method of Test for Knock Characteristics of Aviation Fuels (D 614 – 44 T).

Proposed Change in Mixture Heater Assembly in Method D 357:

This proposed revision of Section A5(*f*) in the Standard Method of Test for Knock Characteristics of Motor Fuels (D 357 – 45)[1] provides for the use of a mixture thermostat in locations where large fluctuations in line voltage are encountered. This revision was approved by Section IV on Detonation, and submitted to letter ballot in Technical Committee A; of the 37 members, 24 returned their ballots, of whom 20 have voted affirmatively, 0 negatively, and 4 marked their ballots "not voting." The proposed revision is as follows:

Section A5 (*f*).—Add the following new paragraph:

> In locations where line voltage fluctuations are small, the mixture temperature can be controlled satisfactorily by manual adjustment of the rheostat. Where large fluctuations are encountered, use of the mixture thermostat,[a] available as optional equipment, is recommended. This device consists of (*1*) a bimetallic thermostatic unit incorporated in a $\frac{3}{8}$-in. spacer, which is inserted between the intake manifold and the intake port of the cylinder, and (*2*) an electronic relay unit mounted on, preferably behind, the instrument panel.

Proposed Changes in Exhaust System Specifications for Methods D 357 and D 614:

Resonance or tuning of the exhaust pipe may affect engine performance by producing pressure waves which affect the scavenging of combustion products from the cylinder. Depending on the tuning present, an appreciable positive or negative pressure can exist during the period of exhaust-valve opening. In order to obtain data which are reproducible from one laboratory to another, it is important that all knock-test engines operate under the same test conditions. If the tolerances in the exhaust system specifications for these engines permitted different conditions of resonance from one engine to another, then these engines would not be operating under the same test conditions.

The Coordinating Fuel Research Committee, in the fall of 1943, formed several panels to investigate in this respect the adequacy of the specifications for the exhaust system now prescribed in the Standard Method of Test for Knock Characteristics of Motor Fuels (D 357 – 45)[1] and the Tentative Method of Test for Knock Characteristics of Aviation Fuels (D 614 – 44 T).[2] Tests were conducted on a single-cylinder supercharged C.F.R. engine, connected to a dynamometer, and equipped with fuel and air-flow measurement apparatus. Various lengths of exhaust pipe up to the limit prescribed in the test methods were tried, and the effect on engine performance noted. The significant data obtained are presented in Table I.

These data show that the air consumption of the engine varied as the pipe length was changed, indicating that different conditions of resonance were obtained, which affected engine performance. Present test methods specify only a maximum length of pipe. Therefore, it was evident that all engines were not operating under the same conditions, and that a means should be provided for removing this variable.

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[1] 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[a] Detailed information on this device can be obtained from the Waukesha Motor Co., Waukesha, Wis.

[2] 1944 Book of A.S.T.M. Standards, Part III.

In order to minimize the effect of resonance, a 1-cu. ft. surge tank was installed in the exhaust system, as close to the engine as practicable. Test data obtained with various exhaust-pipe lengths are given in Table II.

TABLE I.—EXHAUST SYSTEMS CONFORMING TO PRESENT SPECIFICATIONS EFFECT OF EXHAUST PIPE LENGTH ON ENGINE PERFORMANCE.[a]

Pipe Length, ft.	Power Output, IMEP, psi.	Air Flow, lb. per hr.
12	167	87.2
15	167	86.8
18	167	86.4
20	166.3	86.0
22	165	85.3

[a] Engine operating conditions same for each test. Absolute manifold pressure 40 in. of mercury, fuel-air ratio at maximum power point on constant boost curve.

These data indicate that exhaust pipe length had little if any effect on air consumption, or horsepower output. It was, therefore, concluded that it would be advisable to include a surge tank of this size in the specifications for the exhaust system. Moreover, it was agreed that these results, while applying to a supercharged C.F.R. engine operating at 1800 rpm., were also applicable to the engines used in A.S.T.M. Methods D 357 and D 614.

Data substantiating these conclusions have been offered by several laboratories. In addition to observing a change in engine performance with various pipe lengths under the present specifications, it was found that static back pressures varied up to 30 in. of water, between different installations. The addition of a surge tank minimized these variances.

The changes summarized in the proposed revision given below were approved by the Coordinating Fuel Research Committee in February, 1945, without exchange test rating data, since it was felt that these changes should not affect ratings as there were probably as many engines in service, the performance of which was adversely affected by resonance as there were those whose performance was aided, and, therefore, the proposed system represented a mean. A number of laboratories have used the proposed system over a period of six months, and report no effect on ratings.

TABLE II.—PROPOSED EXHAUST SYSTEM SPECIFICATIONS INCLUDING 1 CU. FT. SURGE TANK EFFECT OF EXHAUST PIPE LENGTH ON ENGINE PERFORMANCE.[a]

Pipe Length, ft.	Power Output, IMEP, psi.	Air Flow, lb. per hr.	Static Back Pressure in Water, in.
Open to atmosphere...	163	85.7	2
7....................	162	85.7	3
12....................	163	85.3	1
15....................	162.5	85.3	1
20....................	162	85.3	1
23....................	162	85.3	2
30....................	163	85.6	1

[a] Engine operating conditions same for each test. Absolute manifold pressure 40 in. of mercury, fuel-air ratio at maximum power point on constant boost curve.

It is accordingly proposed that Section A10 in A.S.T.M. Methods D 357 and D 614 be revised to read as follows:

A10. *Exhaust System.*—A separate exhaust system shall be provided for each engine. The system shall consist of a flexible pipe, a surge tank, Fig. 1,[3] and a discharge pipe.

(*a*) *Flexible Pipe.*—A flexible pipe not less than $1\frac{1}{4}$ in. in internal diameter, and not exceeding 30 in. in length shall be used to connect the engine exhaust port and the surge tank. The special flange and spacer shown in Fig. 2 shall be used for the connection to the surge tank.

(*b*) *Spacer.*—The spacer used shall be either a brass ring for water injection or a transite spacer. Experience has shown that the use of water injection is advantageous.

(*c*) *Surge Tank.*—The surge tank, which shall have an inside diameter of not less than 10 in., an outside diameter of not less than $10\frac{3}{4}$ in., and a volume of not less than 1 cu. ft. may be mounted either vertically or horizontally, but must be rigidly supported. If mounted vertically, as shown in Fig. 1, the exhaust is discharged through the top flange, and water through the pedestal. This mounting is adapted to installations where the discharge pipe passes through the roof of the building.

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[3] When this revision is adopted and incorporated in the methods these figures will be renumbered in Method D 357 as Figs. 2, 3, and 4, and in Method D 614 as Figs. 3, 4, and 5.

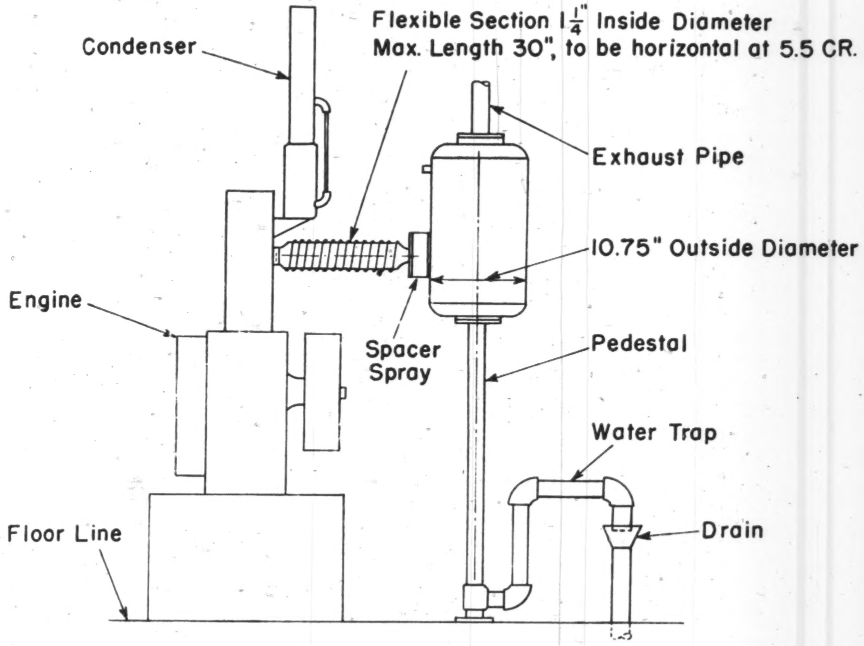

Flexible Section 1 1/4" Inside Diameter
Max. Length 30", to be horizontal at 5.5 CR.
Condenser
Exhaust Pipe
10.75" Outside Diameter
Engine
Spacer
Spray
Pedestal
Water Trap
Drain
Floor Line

FIG. 1.—Exhaust System.

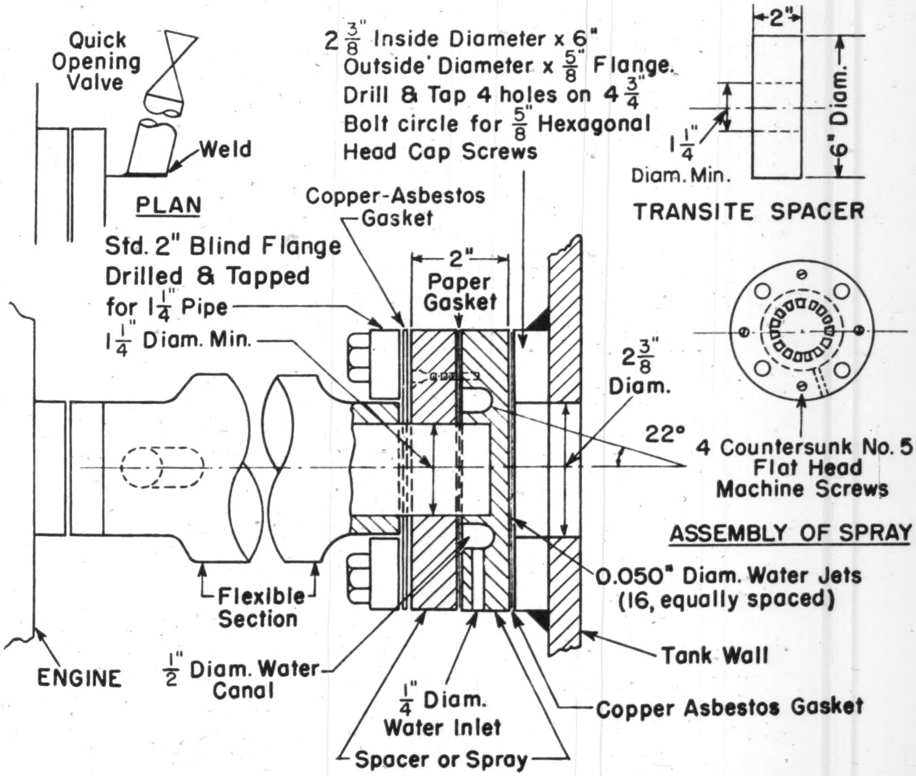
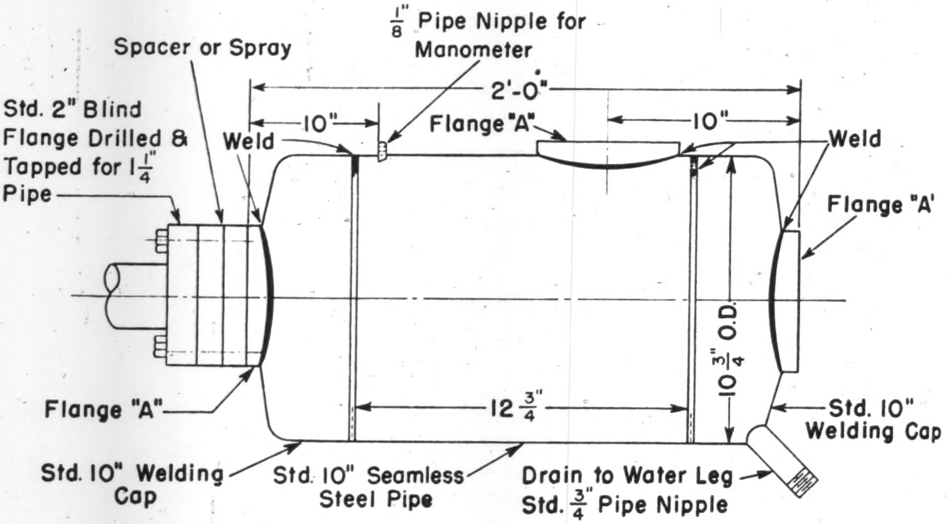

Quick
Opening
Valve
Weld
PLAN
2 3/8" Inside Diameter x 6"
Outside Diameter x 5/8" Flange.
Drill & Tap 4 holes on 4 3/4
Bolt circle for 5/8" Hexagonal
Head Cap Screws
2"
1 1/4"
Diam. Min.
6" Diam.
TRANSITE SPACER
Copper-Asbestos
Gasket
Std. 2" Blind Flange
Drilled & Tapped
for 1 1/4" Pipe
1 1/4" Diam. Min.
2"
Paper
Gasket
2 3/8"
Diam.
22°
4 Countersunk No. 5
Flat Head
Machine Screws
ASSEMBLY OF SPRAY
0.050" Diam. Water Jets
(16, equally spaced)
Flexible
Section
Tank Wall
ENGINE
1/2" Diam. Water
Canal
1/4" Diam.
Water Inlet
Copper Asbestos Gasket
Spacer or Spray

FIG. 2.—Flexible Pipe and Spacer.

Where the exhaust is to be discharged into ducts in the floor, the pedestal may serve as the discharge pipe. In case water must be removed from the exhaust, the pedestal pipe should extend into the surge tank to a point above the exhaust inlet. In such installations the drain tap serves as the water outlet, and a trap should be provided in the drain line.


$\frac{1}{8}$" Pipe Nipple for Manometer
Spacer or Spray
Std. 2" Blind Flange Drilled & Tapped for 1$\frac{1}{4}$" Pipe
2'-0"
10"
Weld
Flange "A"
10"
Weld
Flange "A'
10$\frac{3}{4}$" O.D.
Flange "A"
12$\frac{3}{4}$"
Std. 10" Welding Cap
Std. 10" Welding Cap
Std. 10" Seamless Steel Pipe
Drain to Water Leg Std. $\frac{3}{4}$" Pipe Nipple

NOTE:
Tank to be Lagged if Water Injection Not Used.
Flange "A" - 2$\frac{3}{8}$" Inside Diameter x 6" Outside Diameter x $\frac{5}{8}$" Flange. Drill & Tap 4 Holes on 4$\frac{3}{4}$" Bolt Circle for $\frac{5}{8}$" Hexagonal Head Cap Screws.

FIG. 3.—Exhaust System Surge Tank.

Should it be more convenient to mount the surge tank horizontally, the exhaust may be discharged through either the top or the end flange, Fig. 3. A trap should be provided in the drain line.

(*d*) *Exhaust Back Pressure.*—The back pressure at the surge tank shall not exceed 10 in. of water.

(*e*) *Discharge Pipe.*—The discharge pipe shall have a minimum inside diameter of 2 in. and a maximum length of 30 ft. measured from the surge tank. Elbows, or other restrictions, must be avoided in order to comply with Paragraph (*d*). A straight-through muffler may be used, if compliance with Paragraph (*d*) is obtained therewith.

NOTE.[4]—If it is impractical, because of laboratory construction or location, to conform to the 30-ft. maximum length for the discharge pipe, or to the requirement of a separate exhaust system for each engine, the exhaust back pressure at the surge tank nevertheless shall not exceed 10 in. of water, and resonance shall not occur in the system. To check for resonance, install a quick-opening $\frac{3}{4}$-in. pipe valve in the flexible exhaust pipe, as shown in Fig. 2. If the indicated knock is altered appreciably when the valve is opened, discharging the exhaust to the atmosphere, resonance is indicated, and the system must be altered to correct it.

The above proposed changes in the exhaust system were approved by a majority of the members of Section IV on Detonation, and were submitted to letter ballot of Technical Committee A; of the 37 members, 24 returned their ballots with the following results: Method D 357, 17 affirmative, 3 negative, and 4 ballots marked "not voting"; Method D 614, 17 affirmative, 2 negative, and 5 ballots marked "not voting."

Respectfully submitted on behalf of the technical committee,

C. B. VEAL,
Chairman.

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[4] This note will be numbered Note 9 in Method D 357, and Note 5 in Method D 614.

RESULTS OF TESTS ON METHOD FOR ESTIMATING MAXIMUM POUR POINTS OF LUBRICATING OILS CONTAINING POUR POINT DEPRESSANTS

SUBMITTED BY SUBCOMMITTEE XVI

Subcommittee XVI on Cloud and Pour Test recommends that the appended Proposed Method of Test for Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants,[1] as developed by members of the subcommittee, be published as information only.

Since 1917, the subcommittee has recognized, especially in the case of black oils and cylinder stocks, the effect of thermal history on pour point. The present A.S.T.M. Method of Test for Cloud and Pour Points (D 97 – 39)[2] in recognition of this fact, contains a "Special Procedure for Black Oils, Cylinder Stocks and Nondistillate Fuel Oils." In 1934, with increasing use of pour point depressants, recognition was given to the greater sensitivity of oils containing them by providing a slower cooling rate. All of the foregoing serves to emphasize the inadequacy of the present method for predicting the pour points of oils containing depressants when subjected to a fluctuating thermal cycle.

For the past year and a half, the members of Subcommittee XVI cooperated in a search for a better method and at least seven distinctly different procedures were evaluated. Samples of 19 carefully chosen oils were made available for study and a preliminary report at the June, 1944, meeting led to the conclusion that further work should be directed to the procedure designated later in this report as "Method D" (as distributed June, 1944). Since that time seven laboratories have reported results on the 19 oils by this procedure. These data are given in Table I.

In the course of the work, and from the comments of those participating, it became evident that certain minor changes were desirable. These have been incorporated in the appended Proposed Method.[1]

Three of the cooperating laboratories have applied this final Method to the 19 oils and obtained the results given in Table II. In Table III average A.S.T.M. pour points from Table I, average stable pour points from Table I (obtained by Method D (June, 1944)), individual and average maximum pour points from Table II, results of the Standard Oil Co. of N. J. type V test, and estimated stable pour points from such field testing as is available to date, are brought together for comparison.

The determination of temperatures at which to make observations on samples under test was based on the A.S.T.M. pour point of the oil in question in the procedure for "Method D" (June, 1944). The experimental basis for establishing these points of observation is now obtained by examining the samples at each five-degree interval during cooling in the first cycle. This change materially reduces the over-all testing time. Maximum pour point may be obtained with a pair of samples at the same time that A.S.T.M. pour point is determined on a third sample and all testing, including preparation of samples, can be completed in a maximum time of 8 hr.

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[1] See p. 244.

[2] 1944 Book of A.S.T.M. Standards, Part III.

TABLE I.—RESULTS OF CLOUD AND POUR POINT TESTS.

All results are in degrees Fahrenheit.

Coopera-ting Labora-tories	Oil Sample								
	HC-1	HC-2	HC-3	IC-4	IC-5	LC-6	7	8	9
STABLE POUR POINT—METHOD D[b]									
A	+5, +5	+10, +5	+10, +15	−5, 0	−10, −25	−10, −15	−25, −20	−5, −10	+10, +20
B	+20	+15	+15	+5	−10	−5	−25	+5	+20
C	+20	−5	0	−5	−20	−10	−20	+5	+20
D	+15, +15	+10, +10	+10, +10	0, 0	−20, −20	−5, −5	−25, −25	0, 0	+10, +10
E	+15	0	+15	−5	−20	−10	−25	−10	+15
F	+10	+15	+15	+5	−5	−10	−15	+5	+20
G	+20, +15	+10, +15	+20, +15	+10, 0	0, −15	0, −10	−15, −15	−5, −15	+15, +10
Average	+15	+10	+15	0	−15	−10	−20	−5	+15
A.S.T.M. CLOUD POINTS—METHOD D 97									
A	36	36	36	18	14	16	16	42	20
B	34	34	34	20	14	6	16	46	26
C	30, 32	30, 32	30, 32	18, 20	15, 15	6, 6	16, 14	44, 44	24, 20
D	28, 28	32, 32	30, 30	20, 20	10, 10	8, 8	12, 12	46, 46	24, 24
E	34, 32	30, 30	30, 32	18, 18	12, 14	6, 6	14, 14	44, 44	18, 20
F	28	28	28	16	4	2	14	30	20
G[a]	32	36	32	20	8	8	16	48	26
Average	32	32	32	18	12	8	14	44	22
A.S.T.M. POUR POINTS—METHOD D 97									
A	−35, −25	−15, −15	−20, −15	−25, −20	−30, −25	−20, −20	−25, −30	−35, −25	−10, −10
B	−30	−15	−20	−20	−30	−25	−25	−25	−15
C	−25, −30	−15, −20	−20, −20	−20, −25	−25, −30	−25, −25	−30, −30	−30, −25	−10, −10
D	−35, −35	−15, −15	−20, −20	−20, −20	−30, −30	−25, −25	−30, −30	−30, −30	−10, −15
E	+20, −25	−20, −25	−20, −20	−20, −20	−30, −25	−20, −20	−25, −25	−35, −30	−10, −10
F	−20, −25	−15, −15	−15, −15	−25, −25	−30, −30	−20, −20	−25, −25	−30, −30	−5
G[a]	−25	−15	−15	−15	−25	−25	−20	−20	−5
Average	−25	−15	−20	−20	−30	−20	−25	−30	−10

Coopera-ting Labora-tories	Oil Sample								
	10	11	12	13	14	15	16	17	18	HC-12
STABLE POUR POINT—METHOD D[b]										
A	+10, +10	+10, +15	+5, +5	−15, −10	−20, −10	0, +10	−20, −30	0, +5	−15, 0	+20, +25
B	+15	+15	+15	−10	−10	+15	−25	+10	0	−
C	+15	+20	+5	−20	−20	+5	−25	+5	0	+25
D	+10, +10	+10, +10	+5, +5	−20, −20	−15, −15	+5, +5	−20, −25	+5, +5	−5, −5	+25, +25
E	+15	+20	+15	−20	−20	+10	−25	+10	0	−
F	+20	+20	+20	−5	−10	+10	−5	+15	+10	−
G	+15, +10	+15, +15	+20, +10	−10, −15	−10, −15	+5, +15	−15, −20	+5, +10	+10, +5	+25, +25
Average	+15	+15	+10	−15	−15	+10	−20	+5	0	+25
A.S.T.M. CLOUD POINTS—METHOD D 97										
A	24	24	30	20	26	44	18	20	30	34
B	32	24	28	16	24	34	16	24	30	36
C	22, 22	24, 22	28, 30	18, 18	22, 22	32, 32	16, 16	18, 22	30, 32	32, 32
D	20, 20	26, 26	−	−	−	−	−	−	−	30, 30
E	18, 20	20, 22	−	−	−	−	−	−	−	32, 32
F	20	18	−	−	−	−	−	−	−	32
G[a]	24	22	26	18	24	30	16	20	30	38
Average	22	22	28	18	24	32	16	20	30	32
A.S.T.M. POUR POINTS—METHOD D 97										
A	−5, −10	−10, −10	−25, −20	−30, −25	−35, −20	−15, −20	−30, −25	−25, −25	−30, −25	+20, +20
B	−10	−10	−20	−25	−25	−20	−30	−30	−25	+20
C	−15, −10	−10, −10	−25, −25	−25, −30	−25, −30	−15, −20	−25, −30	−25, −25	−25, −20	+20, +15
D	−15, −15	−15, −15	−25	−30	−30	−20	−30	−25	−25	+10, +10
E	−15, −15	−15, −10	−25	−25	−25	−20	−30	−25	−25	+10, +20
F	−5	−5	−20	−30	−30	−15	−15	−15	−15	+25
G[a]	−5	−10	−20	−25	−30	−15	−25	−25	−25	+15
Average	−10	−10	−25	−25	−30	−20	−25	−25	−25	+15

[a] Values shown are averages of five separate determinations.
[b] As distributed June, 1944.

TABLE II.—MAXIMUM POUR POINT TEST RESULTS.
All results are in degrees Fahrenheit; also S designates solid and F fluid

Oil sample	HC-1	HC-2	HC-3	IC-4	IC-5	LC-6	7	8	9
LABORATORY A									
Run 1:									
First cycle	S +5, S +5	S +5, S +5	S +15, S +15	S −15, S −15	S −25, S −25	S −25, S −25	S −30, S −30	S −15, S −15	S +10, S +10
Second cycle	S +10, F +15	F +10, F +15	F +20, F +20	S −10, F −5	F −20, F −15	S −20, F −15	F −25, F −20	F −10, F −5	F +15, F +20
Third cycle	F +15, F +20	F +10, F +15	F +20, F +20	F −5, F 0	F −20, F −15	F −15, F −10	F −25, F −20	S −10, S −5	F +15, F +20
Maximum pour point	+15	+10	+20	−5	−20	−15	−25	0	+15
Run 2:									
First cycle	S +10, S +10	S +10, S +10	S +10, S +10	S −20, S −15	F −30, F −30	S −25, S −25	F −30, F −30	F −30, F −30	S +5, S +5
Second cycle	F +15, F +20	F +15, F +20	F +15, F +20	F −10, F −5	F −20, F −25	F −20, F −15	F −20, F −25	S −20, S −25	S +10, F +15
Third cycle	F +15, F +20	F +15, F +20	F +15, F +20	S −10, F −5	S −30, S −35	F −20, F −15	F −30, S −35	S −15, S −10	F +15, F +20
Maximum pour point	+15	+15	+15	−5	−25	−20	−30	−5 or above	+15
LABORATORY B									
Run 1:									
First cycle	S +15, S +15	S −5, S −5	S +15, S +15	S −10, S −10	S −25, S −25	S −20, S −25	S −30, F −30	S −15, S −15	S +10, S +10
Second cycle	F +20, S +15	S 0, F +5	F +20, F +15	S −5, F 0	S −20, F −15	F −15, F −10	S −25, F −20	S −10, F −5	F +15, F +20
Third cycle	F +20, S +15	S +5, F +10	F +20, S +15	F 0, F +5	F −15, F −10	S −15, F −10	F −20, F −15	F −5, F 0	S +15, F +20
Maximum pour point	+20	+10	+20	0	−15	−10	−20	−5	+20
LABORATORY C									
Run 1:									
First cycle	S +5	S −5, S −5	S −5, S −10	S −10, S −10	S −20, S −15	S −15, S −15	S −25, S −25	S −10, S −10	S +5
Second cycle	S +10	F 0, F +5	S 0, F +5	S −5, F 0	F −10, F −5	S −10, F −5	F −20, F −15	S −5, F 0	S +10
Third cycle	F +15	S −5, S −10	S +5, F +10	F 0, F +5	S −15, S −20	F −5, F 0	S −30, F −25	S +5, S +10	F +15
Maximum pour point	+15	—	+10	0	−10	−5	−20	+15	+15
Run 2:									
First cycle	S +5	S −5, S −15	S 0, S +5	S −15, S −10	S −25, S −25	S −15, S −15	S −30, S −25	S −20, S −15	S +5
Second cycle	S +10	S 0, F +5	S +10, F +15	S −5, F 0	S −20, F −15	F −10, F −5	F −20, F −15	S −10, F −5	S +10
Third cycle	F +15	S +5, F +10	F +15, F +20	S 0, F +5	F −15, F −10	F −10, F −5	F −20, F −15	S −5, F 0	S +15
Maximum pour point	+15	+10	+15	+5	−15	−10	−20	0	+20
Average maximum pour point	+15	+10	+15	0	−15	−10	−25	0	+15

Oil sample	10	11	12	13	14	15	16	17	18	HC-12
LABORATORY A										
Run 1:										
First cycle	S +5, S 0	S +10, S +10	S +10, S +10	S −30, S −30	F −30, F −30	S −5, S −5	F −30, S −30	S −10, S −5	S −15, S −15	S +20, S +20
Second cycle	S +10, F +15	F +15, F +20	F +15, F +20	S −25, F −20	F −20, F −25	S 0, S +5	F −25, F −20	S 0, S +5	S −10, S −5	....
Third cycle	S +15, F +20	F +15, F +20	F +15, F +20	S −20, F −15	S −30, S −35	S +10, F +15	F −25, F −20	F +10, F +15	S 0, F +5	....
Maximum pour point	+20	+15	+15	−15	−25	+15	−25	+10	+5	+25 or above
Run 2:										
First cycle	S +5, S +5	S +5, S +5	S +5, S +5	S −25, S −20	F −30, S −30	S −5, S −5	S −30, S −30	S 0, S 0	S −15, S −15	S +20, S +20
Second cycle	S +10, F +15	S +10, F +15	S +10, F +15	F −15, F −10	F −25, F −20	S 0, S +5	F −25, F −20	S +5, F +10	S −10, S −5	....
Third cycle	S +15, F +20	F +15, F +20	F +15, F +20	F −15, F −10	F −25, F −20	F +10, F +15	S −25, F −20	S +10, F +15	S 0, F +5	....
Maximum pour point	+20	+15	+15	−15	−25	+10	−20	+15	+5	+25 or above
LABORATORY B										
Run 1:										
First cycle	S +5, S +5	S +10, S +10	S +10, S +10	S −25, S −30	F −30, F −30	S +10, S +10	F −30, F −30	S +5, S +5	S −15, S −10	S +20, S +20
Second cycle	F +10, F +15	F +15, F +20	F +15, F +20	S −20, F −15	F −20, S −25	F +15, F +20	F −20, S −25	F +10, F +15	S −5, S 0	....
Third cycle	S +10, F +15	S +15, F +20	S +15, F +20	S −15, F −10	S −20, F −15	S +15, F +20	S −20, F −15	S +10, F +15	F +5, F +10	....
Maximum pour point	+15	+20	+20	−10	−15	+20	−15	+15	+5	+25 or above
LABORATORY C										
Run 1:										
First cycle	S +5, S +5	S +10, S +15	S +10, S +5	S −20, S −15	S −35, S −35	S 0, S −5	S −30, S −30	S −5, S −5	S −10, S −10	S +20, S +20
Second cycle	S +10, F +15	F +20, F +15	F +15, S +10	F −10, F −5	S −30, S −25	S +5, F +10	S −25, F −20	S 0, F +5	S −5, S 0	S +20, S +20
Third cycle	F +15, F +20	S +10, S +5	F +15, F +20	F −10, F −5	S −20, F −15	F +10, F +15	F −20, F −15	S +5, F +10	S +5, F +10	....
Maximum pour point	+15	+15	+15	−10	−15	+10	−20	+10	+10	+25 or above
Run 2:										
First cycle	S +10, S +5	S +5, S +5	S +5, S +5	S −20, S −20	S −30, S −30	S +5, S +5	S −30, S −30	S 0, S +5	S −15, S −15	S +15, S +15
Second cycle	S +15, F +20	S +10, F +15	S +10, F +15	F −15, F −10	S −30, F −25	F +10, F +15	F −25, F −20	F +10, F +15	S −10, S −5	S +20
Third cycle	F +20, F +20	S +15, F +20	F +15, F +20	F −15, F −10	F −25, F −20	S +10, F +15	F −25, F −20	F +10, F +15	S 0, F +5	....
Maximum pour point	+20	+20	+15	−15	−25	+15	−25	+10	+5	+25 or above
Average maximum pour point	+20	+15	+15	−15	−20	+15	−20	+10	+5	+25 or above

TABLE III.—RESULTS OF POUR POINT TESTS BY VARIOUS METHODS.
All results are in degrees Fahrenheit.

Oil sample	HC-1	HC-2	HC-3	IC-4	IC-5	LC-6	7	8	9	10	11	12	13	14	15	16	17	18	HC-12
Average A.S.T.M. pour points (from Table I)	−25	−15	−20	−20	−30	−20	−25	−30	−10	−10	−10	−25	−25	−30	−20	−25	−25	−25	+15
Average stable pour points (from Table I)	+15	+10	+15	0	−15	−10	−20	−5	+15	+15	+15	+10	−15	−15	+10	−20	+5	0	+25
Individual maximum pour points (from Table II):																			
Laboratory A:																			
Run 1	+15	+10	+20	−5	−20	−15	−25	0	+15	+20	+15	+15	−15	−25	+15	−25	+10	+5	+25 or above
Run 2	+15	+15	+15	−5	−25	−20	−30	−5 or above	+15	+20	+15	+15	−15	−25	+10	−20	+15	+5	+25 or above
Laboratory B	+20	+10	+20	0	−15	−10	−20	−5	+20	+15	+20	+20	−10	−15	+20	−15	+15	+5	+25 or above
Laboratory C:																			
Run 1	+15	0	+10	0	−10	−5	−20	+15	+15	+15	+15	+15	−10	−15	+10	−20	+10	+30	+25 or above
Run 2	+15	+10	+15	+5	−15	−10	−20	0	+20	+20	+20	+15	−15	−25	+15	−25	+10	+5	+25 or above
Average maximum pour points (from Table II)	+15	+10	+15	0	−15	−10	−25	0	+15	+20	+15	+15	−15	−20	+15	−20	+10	+5	+25 or above
Std. Oil N. J. Type V	+20	−10	F −25	0	−5	−5	−15	F −25	+10	+10	+15	+10	−20	F −25	0	F −25	−5	−10	−5
Estimated stable pour points (Jan. 15, 1945) from field data	+25	−10	F −13	−5	F −13	−10	−20	+25	+15	+15	+15	+25	−5	+20	+25	F −13	F −13	−5	−10

Instead of the +40 F. bath called for in the June, 1944, procedure, the proposed Method requires the use of a bath at +30 F. for the warming cycles. This change permits a simplification of apparatus requirements since the +30 F. bath stipulated in A.S.T.M. Method D 97 may be employed. The data in Table III demonstrate that no significant change in test results is involved thereby.

By having the Proposed Method for maximum pour point state that whenever a sample is observed solid at +20 F., testing of that sample may be discontinued and its maximum pour point reported as "+25 F. or above," all oils possessing higher stable pour points are specifically accounted for and the testing time for many others will be shortened. For production control work, time can be saved by discontinuing the test at any point where a sample is observed to be solid at the required maximum pour point of the particular oil in question, whatever that temperature may be.

Comparison of data in Tables I and II shows clearly that the modifications in test procedure adopted since the June, 1944 draft, in addition to reducing apparatus requirements and over-all testing time, have served to increase materially the precision and reproducibility of the test without significantly altering the final test results. Comparing average maximum pour points by the Proposed Method with average stable pour points by the old procedure (Table III) shows exact agreement on ten of the oils and only five degrees difference on the other eight. In the latter case, two oils with good pour point stability (Nos. 7 and 14) show maximum pour points 5 F. lower than the stable pour points obtained by the June, 1944, procedure while the remaining six oils, all bad with regard to pour point stability, are shown to be 5 F. higher by the Proposed Method.

The test for maximum pour point covers a range from −35 F. to +25 F. and is limited to SAE No. 10 and SAE No. 20 grade oils, which contain added pour point depressants. These represent the oils which most frequently exhibit the phenomenon of pour point reversion. It is the consensus that the pour point obtaining under field storage conditions will usually fall between the maximum pour point determined by the Proposed Method and the A.S.T.M. pour point obtained by Method D 97. The 19 oils studied are under field tests at several locations and a final report of results obtained will be presented later.

The claim of a degree of reproducibility substantially equal to that obtained with A.S.T.M. Method D 97 is perhaps better than had been expected for a pour point reversion test, but it is adequately supported by the data in Table II. It may be noted by examination of Table II that laboratory A checked its results within 5 F. without exception on the 19 oils while the results in laboratory C show three discrepancies. Of these, the test on oil sample HC-2, where a maximum pour point of 0 F. is reported, is discounted because of an error in the observations during the third cycle. The sample and duplicate were found to be solid at −5 F. and −10 F. in the third cycle, while the Proposed Method calls for these observations to be made at 0 F. and +5 F. at which a solid point presumably would have been obtained. There is no explanation of the −15 F. and −25 F. results obtained by the same laboratory on oil sample No. 14, but the +15 F. result obtained on sample No. 8 is so far out of line with all other results on the same oil that it can reasonably be questioned.

Referring further to sample No. 8, Table II, a point may be brought out which could eventually require a modification of the test procedure. In the second test by laboratory A the sample and duplicate were both solid in both the second and third cycles and the maximum pour point had to be reported as −5 F. or above. A third test on oil No. 8 then gave:

First cycle	Solid − 20 F.,	Solid − 20 F.
Second cycle	Solid − 15 F.,	Fluid − 10 F.
Third cycle	Solid − 10 F.,	Solid − 5 F.
Maximum pour point		0 F. or above

The question raised by such results is whether or not it is advisable to have the test procedure stipulate an additional fourth cycle when results such as these are obtained. However, it is not felt that the present data fully justify such a step and that it would be preferable to await accumulation of additional data before making the decision. Attention is called to the fact that sample No. 8 is the most unpredictable of the 19 oils and field data on this sample will be of particular interest.

Obviously, final definition of precision and reproducibility of the present procedure for maximum pour points must await results of current field testing and reports from wider application of the test. It is for the latter purpose that publication of the test procedure as information only is requested.

Respectfully submitted, on behalf of Subcommittee XVI,

L. C. BEARD, JR.
Chairman.

APPENDIX I

PROPOSED METHOD OF TEST FOR MAXIMUM POUR POINTS OF LUBRICATING OILS CONTAINING POUR POINT DEPRESSANTS[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. This method of test is intended to measure the highest temperature at which SAE 10 and SAE 20 grade oils containing added pour point depressants will solidify when the oil is subjected to cyclic temperature changes.

NOTE 1.—The actual temperature at which an oil will solidify under commercial conditions of storage can be expected to fall somewhere between the maximum pour point determination by this method and the pour point determined by A.S.T.M. Method D 97.[2]

Definition

2. (*a*) *Pour Point.*—The temperature 5 F. above that at which a petroleum oil will not flow when chilled without disturbance at specified cooling rates.

(*b*) *Maximum Pour Point.*—That temperature 5 F. above the highest temperature at which an oil can be found not to flow when alternately cooled and warmed under definitely prescribed conditions.

Outline of Method

3. The oil is cooled to -30 F. and then three times taken through a cycle in which its temperature is raised to $+20$ F. and cooled to -30 F. During each of the last three cooling steps, the condition of the oil is observed at prescribed temperatures when the test jar is tilted. The temperature 5 F. above that at which no flow is observed is recorded as the pour point. The highest of the recorded pour points is reported as the maximum, regardless in which cooling step it was observed.

Apparatus

4. (*a*) *Test Jar, Jacket,* and *Cooling Baths* for maintaining temperatures between 30 and 35 F. and -70 and -60 F. The apparatus shall be as specified in A.S.T.M. Method D 97,[2] but shall be assembled as illustrated in Fig. 1.

(*b*) *Thermometers.*—Low Cloud and Pour test thermometer for measuring test temperatures shall have a range of -70 to $+70$ F., and conform to the specifications for A.S.T.M. thermometer E 1(6 F – 39). Any suitable thermometer may be used for measuring bath temperatures.

Procedure

5. (*a*) *Preparation.*—Dry the inside of each jacket and place a clean dry insulating disk on the bottom of each. Clean and dry the ring gasket and place it on the test jar at such a point that it will be nearly flush with the top of the jacket when the jar is inserted. Pour the oil sample at room temperature into the test jar in quantity sufficient to fill the jar to a point between the two etched lines (2 to $2\frac{1}{4}$ in. above bottom). Stop-

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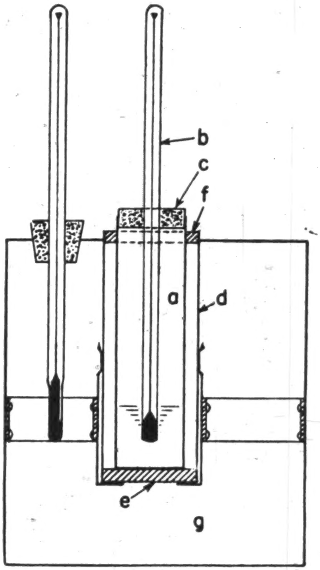
[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1945.

[2] 1944 Book of A.S.T.M. Standards, Part III.

per the jar tightly by means of a cork which supports the test thermometer in a vertical position in the center of the jar. Adjust the thermometer so that it is immersed in the oil to a point $\frac{1}{8}$ in. above the beginning of the capillary. Prepare a duplicate sample in the same manner.

(*b*) *Initial Cooling.*—Place the test jars directly in the jackets in the −70 to −60 F. bath allowing each jar to sit on the insulating disk, and seal the annular opening at the top by means of the ring gasket as shown in Fig. 1. Allow the samples to remain undisturbed until the oil temperatures reach −30 F. If the two samples do not reach this point at the same moment, transfer both to the next bath when the slower cooling one has reached −30 F.



a—Test jar.
b—Thermometer.
c—Cork stopper.
d—Jacket.
e—Disk.
f—Ring gasket.
g—Cooling bath.

FIG. 1.—Apparatus for Maximum Pour Point Test.

NOTE 2.—When transfer is made of the samples from one bath to another the test jar shall always be placed in the jacket, *not* directly into the cooling medium.

(*c*) *First Cycle.*—When the oil temperature reaches −30 F., transfer the samples to a bath at +30 F. and allow them to remain undisturbed in this bath until a temperature of +20 F. is reached. As each sample reaches +20 F. transfer it immediately to the bath at −60 F. Beginning with the oil at a temperature of +20 F., carefully remove the test jar from the bath and tilt it just enough to ascertain if there is a movement of the oil. If movement is observed, return the jar to the −60 F. bath. Do not consume more than 3 sec. for the complete operation of removal, observation, and replacement. Repeat this observation for flow at each of the succeeding lower 5 F. temperatures. When the oil does not appear to flow as the jar is tilted, hold the test jar in a horizontal position for 5 ± 0.1 sec., observe the oil for movement and immediately return it to the cooling bath. If the oil in the test jar shows no movement under this last condition, record it as being solid at the temperature indicated by the test thermometer; otherwise record the oil as being fluid.

(*d*) *Second Cycle.*—When the oil temperature reaches −30 F., transfer each test jar to a bath at +30 F. and allow it to remain undisturbed in that bath until the samples reach a temperature of +20 F. As each sample reaches +20 F., transfer it immediately to the bath at −60 F. If both samples were fluid in the first cycle, observe the condition of the one sample at −20 F. and the condition of the other at −25 F. If either or both samples were observed to be solid during the first cycle, observe the condition of one sample at 5 F. above the higher solid point recorded and the condition of the other at 10 F. above the same point. Record the condition of the two samples as solid or fluid at the temperature of observation.

(*e*) *Third Cycle.*—When the oil temperature reaches −30 F., transfer each test jar to a bath at +30 F. and allow it to remain undisturbed in that bath until the samples reach a temperature of +20 F. As each sample reaches +20 F. transfer it immediately to the bath at −60 F. If both samples were recorded as fluid in the first cycle and in the second cycle, observe the condition of the one sample at −30 F. and the condition of the other at −35 F. If either or both samples were recorded as being solid during the second cycle, observe the condition of the one sample at 5 F. above the higher solid point recorded in the second cycle and the condition of the other sample at 10 F. above the same point. If either or both samples were recorded as being solid in the first cycle and subsequently both were recorded as being fluid in the second cycle, observe the condition of one at 5 F. and the other at 10 F. above the higher solid point recorded in the first cycle. Record the condition of the samples as solid or fluid at the temperature of observation described above.

Reporting

5. Report as the maximum pour point of the oil under test that temperature 5 F. above the highest temperature at which either sample was observed at any time to be solid during the course of the test. If the highest solid point observed was +20 F., the maximum pour point shall be reported as "+25 F. or above." If the sample and duplicate were fluid at all observations, the maximum pour point shall be reported as "−35 F. or below."

NOTE 3.—If at any time during the test an oil is found to be solid at +20 F., testing of this oil may be discontinued and it may be reported as having a maximum pour point of "+25 F. or above."

Reproducibility of Results

6. Individual results of the test for maximum pour point on the same oil in any one laboratory may vary by 5 F. and in different laboratories by 10 F., although the average of three or more results in different laboratories should show a difference between averages no greater than 5 F.

APPENDIX II

PROPOSED METHOD OF TEST FOR TOTAL OLEFINIC AND AROMATIC HYDROCARBONS IN GASOLINE[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. This method of test is intended for the determination of olefinic plus aromatic hydrocarbons in gasolines or other hydrocarbon mixtures that have 95 per cent distillation temperatures of 205 C. (400 F.) or lower by A.S.T.M. Method D 86, Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products.[2] It is applicable to finished motor and aviation fuels, to base and blending stocks, and to any narrow-boiling hydrocarbon mixture falling within this boiling range limitation. The method is not applicable to determinations above 98.5 per cent olefins plus aromatics if a 10-ml. sample is used nor above 97.0 per cent if a 5-ml. sample is used (Note 1).

Note 1.—The ASTM has no correlation between this method and the similar test (aromatic hydrocarbon content of Stoddard Solvent) described in A.S.T.M. Specifications D 484, for Stoddard Solvent.[3]

Outline of Method

2. A measured volume of sample is shaken, at the temperature of melting ice, with a solution of phosphorous pentoxide in concentrated sulfuric acid. The contraction in volume due to the absorption of olefinic and aromatic hydrocarbons in the acid mixture is a measure of the total content of those constituents (Note 2).

Note 2.—The contraction in volume actually measures total olefins and aromatics present in the sample plus any volume change which occurred when these olefins and aromatics were mixed with the saturated hydrocarbons. The maximum volume change known among hydrocarbons of this boiling range is 0.6 per cent expansion for a 2:3 mixture of benzene and saturates. However, the volume change is generally less than 0.3 per cent; hence it is usually less than the precision of the method and may be neglected.

Apparatus

3. (*a*) *Standard and Precision Sulfonation Flasks* meeting the requirements shown in Figs. 1, 2, and 3.

(*b*) *Pipettes* of 5 and 10-ml. capacities, calibrated to deliver 5.0 ± 0.05 ml. and 10.0 ± 0.05 ml. of water at 20 C., respectively.

(*c*) *Centrifuge*, mechanical or hand-driven, capable of a speed of 1000 rpm., and equipped with metal cups having a minimum inside diameter of $1\frac{1}{2}$ in. The construction of the centrifuge shall be such that no part of the neck of the flask touches the centrifuge head when the centrifuge is in motion. (Note 3.)

Note 3.—The standard two-cup, hand-driven, milk-test centrifuge for 6-in. Babcock bottles may be used. When the standard sulfonation flasks are being centrifuged, the penny heads must be aligned in the same vertical plane to prevent breakage.

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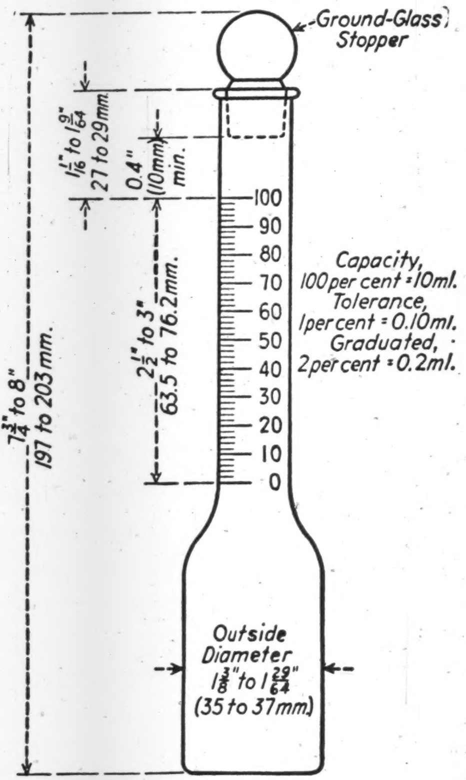
[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1945.

[2] 1945 Supplement to Book of A.S.T.M. Standards, Part III.

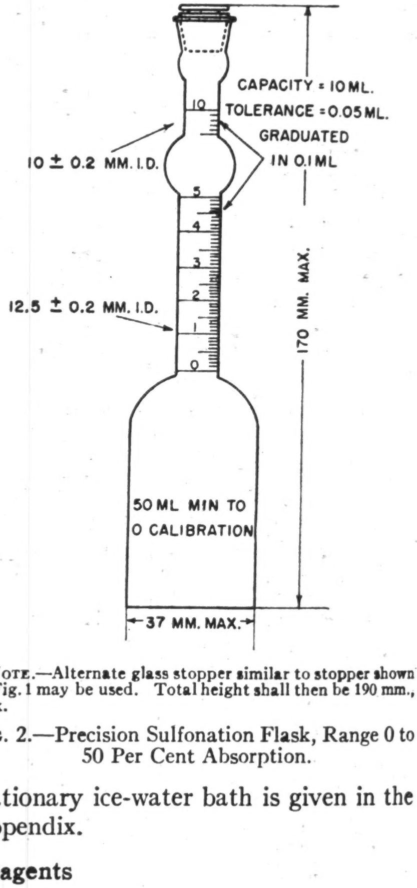
[3] 1944 Book of A.S.T.M. Standards, Part III.

(*d*) *Mechanical Shaker* having a horizontal stroke 3 ± 0.5 in. in length and a speed of 250 ± 25 cycles per sec., each cycle consisting of one forward and one return stroke. The shaker shall shake the desired number of sulfonation flasks, rigidly clamped in an upright position, while they are immersed to a depth of 3.25 ± 0.25 in. in an ice-water bath. The clamp for the flask should include a cylindrical metal cup, having a disk of sponge rubber in the bottom, which shall be inverted over the stopper and upper neck of the sulfonation flask. This arrangement not only holds the flask in place but also serves as a relief valve, should excessive pressures develop in the flask during shaking. The ice-water bath may be either a small ice pack that is shaken with the sulfonation flask or a large stationary bath through which the carrier for the sulfonation flasks moves; a description of a shaking machine with stationary ice-water bath is given in the Appendix.


Ground-Glass Stopper
1 1/16" to 1 9/64"
27 to 29mm.
0.4" (10mm) min.
2 1/2" to 3"
63.5 to 76.2mm.
7 3/4" to 8"
197 to 203mm.
100
90
80
70
60
50
40
30
20
10
0
Capacity, 100 per cent = 10ml.
Tolerance, 1 per cent = 0.10ml.
Graduated, 2 per cent = 0.2ml.
Outside Diameter 1 3/8" to 1 29/64" (35 to 37mm)

The volume of the flask to the zero calibration mark on the neck should be not less than 50 ml.

FIG. 1.—Standard Sulfonation Flask.


CAPACITY = 10 ML.
TOLERANCE = 0.05 ML.
GRADUATED IN 0.1 ML
10 ± 0.2 MM. I.D.
10
5
4
3
2
1
0
12.5 ± 0.2 MM. I.D.
170 MM. MAX.
50 ML MIN TO 0 CALIBRATION
37 MM. MAX.

NOTE.—Alternate glass stopper similar to stopper shown in Fig. 1 may be used. Total height shall then be 190 mm., max.

FIG. 2.—Precision Sulfonation Flask, Range 0 to 50 Per Cent Absorption.

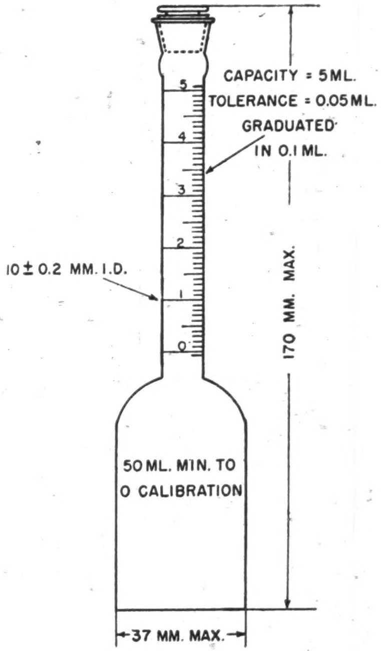
Reagents

4. (*a*) *Sulfonation Acid.*—Prepare by dissolving 30 ± 1 g. of c.p. P_2O_5 in each 70 ± 2 g. of c.p. H_2SO_4 (95 to 96 per cent). If more than a small amount of insoluble residue is obtained, discard the reagent. Store in a 500-ml. glass-stoppered "ether bottle." In storage, keep the ground-glass cap in place to prevent the collection of moisture on the lip of the bottle.

(*b*) *Sulfuric Acid, c.p.* (*95 to 96 per cent H_2SO_4 by weight*).

Test of Procedure Using Check Samples

5. (*a*) *Non-Aromatic Sample.*—Percolate 200 ml. of methylcyclohexane through 50 g. of silica gel packed tightly in a 10-mm. diameter column. Following the procedure given in Section 6, the total absorption (or apparent aromatic content) for this sample should not exceed 1 per cent (Note 4).



NOTE.—Alternate glass stopper similar to stopper shown in Fig. 1 may be used. Total height shall then be 190 mm., max.

FIG. 3.—Precision Sulfonation Flask, Range 48 to 100 Per Cent Absorption.

NOTE 4.—Significant departures from the specified procedure, particularly in regard to the reaction temperature, may yield results that differ from the correct value by as much as 5 per cent. Methylcyclohexane reacts more readily with the acid at temperatures above 0 C. than do paraffins or other naphthenes.

(*b*) *Aromatic Sample.*—Purify a paraffin (*iso*octane, *n*-heptane, etc.) by percolating a 200-ml. portion through 50 g. of silica gel in a 10-mm. column. Place 60 ± 0.1 ml. in a 100-ml. volumetric flask and dilute to volume with pure toluene.[4] Following the procedure given in Section 6, the aromatic content of this sample should be 40 ± 1 per cent and the raffinate should have a refractive index or density within plus or minus 0.0002 of that of the purified paraffin or naphthene used for the blend (Note 5).

NOTE 5.—Sufficient contact between the acid and hydrocarbon is a critical factor affecting the precision of the method, particularly when the aromatic content is about 40 per cent.

Procedure

6. (*a*) Introduce 25 ± 1 ml. of the sulfonation acid into either the standard or precision sulfonation flask (depending on the desired precision) and close the flask with the glass stopper. Place the flask in its holder in the shaking machine so that it is submerged 3.25 ± 0.25 in. in the ice-water bath (0 to 4 C.) and allow it to remain in the bath for at least 5 min. Measure and record the temperature of the sample. By means of a pipette, add 10 ml. of sample to the sulfonation acid, allowing the sample to run slowly down the walls of the flask so that no mixing of the two phases will occur (Note 6). Stopper the flask and secure in place in the shaking machine by means of the clamp (Note 7).

NOTE 6.—A highly volatile sample, such as a C_5, must be cooled in an ice-water bath and transferred to the sulfonation flask by means of a cooled pipette. For this type of sample the preliminary shaking described in Paragraph (*b*) should be modified to one full cycle every 15 sec. for a period of 5 min. in order to assure sufficient contact between the light sample and the acid layer.

NOTE 7: *Caution.*—It is important that the sponge rubber disk be placed between the stopper of the flask and the clamp. Excessive pressure which may develop in blends of high olefin content will push the stopper into the rubber disk and thus release the pressure. If the stopper is fastened rigidly to the flask, breakage may occur.

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[4] Eastman X grade toluene has been found satisfactory.

(*b*) Allow the flask to stand for 5 min. after introduction of the sample into the flask, then cause the shaking machine to make one full cycle (a forward and a return stroke) at the end of each minute for the next 5 min. Then without further interruption allow the flask to be shaken at a rate of 250 ± 25 cycles per min. for the next 20 min. (Note 8).

NOTE 8: *Danger.*—Put on face mask or goggles before proceeding with the next step in the procedure.

(*c*) Vent the flask momentarily while still in the ice-water bath, then immediately remove it from the bath and centrifuge it for 3 min. at approximately 1000 rpm. Pour H_2SO_4 (95 to 96 per cent) down the side of the neck of the flask until the hydrocarbon layer is entirely within the graduated portion of the neck, then centrifuge for an additional 3 min.

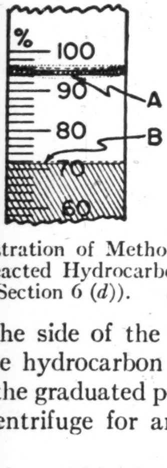

FIG. 4.—Illustration of Method for Reading Volume of Unreacted Hydrocarbon in Sulfonation Flask (see Section 6 (*d*)).

(*d*) Bring the acid-hydrocarbon mixture to a temperature within 1 C. (Note 9) of that at which the sample was measured by immersing the sulfonation flask for 5 min. in a beaker of water maintained at the desired temperature. Place the flask in front of a plain, nonglary, white or light-colored background illuminated by a diffused light. Read the scale to the nearest quarter division (that is, to the nearest 0.05 ml.) on a standard flask, and to the nearest 0.2 division (that is, to the nearest 0.02 ml.) on a precision flask, at the upper and lower levels of the hydrocarbon layer as represented by points *A* and *B* in Fig. 4. Point *A* denotes the nearly flat boundary between the clear hydrocarbon and the darkest part of the air-liquid interface, and point *B* refers to the lower and more distinct interface between the clear hydrocarbon and the sulfonation acid. (In Fig. 4 these readings are, respectively, 9.4 and 7.15 ml.)

NOTE 9.—A temperature change of 1 C. corresponds to a volume change of about 0.1 per cent.

(*e*) If the residual volume is less than 5 ml. and olefins are known to be present in the sample, make a second determination using only 5 ml. of sample.

Calculation and Report

7. (*a*) Calculate the olefin-aromatic content as follows:

Olefin-aromatic content, per cent by volume

$$= \frac{(V - r)100}{V} - \frac{10C}{V}$$

where:

V = milliliters of sample,
r = milliliters of residue, and
C = correction for solubility of residue in the acid (see Table I).

TABLE I.—SOLUBILITY CORRECTIONS (SEE SECTION 7 (*a*)).

$(V - r)100/V$	C
0 to 5	0.7
5 to 20	0.8
20 to 35	0.9
35 to 45	1.0
45 to 60	1.1
60 to 70	1.2
70 to 85	1.3
85 to 100	1.4

(*b*) When results are obtained with both 5 and 10-ml. samples and the former are not more than 1.5 per cent different from the latter, report the values obtained with the 10-ml. sample; otherwise report the results obtained with the 5-ml. sample.

Precision

8. Results should not differ from the mean by more than the following amounts:

Type of Flask	Sample Size, ml.	Repeatability	Reproducibility
Standard	5	2	2
Standard	10	1	1
Precision	5	1	1
Precision	10	0.5	0.5

APPENDIX

SHAKING MACHINE WITH STATIONARY ICE-WATER BATH

The stationary ice bath, as shown in Fig. 5, is mounted from the base of the shaking machine. It consists of a wooden box with an inner metal lining. The metal tank is 16 in. in length, 18 in. in depth and has two partitions of ¼-in. mesh wire screen which divide the bath into three compartments each 6 in. in width. Ice is packed in the two outer compartments and the tank filled with water so that the sulfonation flasks are immersed to a depth of 3½ in. The center compartment, in which the carrier for the sulfonation flasks moves, will then be filled with water free from ice at a temperature of between 0 and 2 C.

The shaking apparatus, with the ice bath removed to illustrate the mounting of the flask carrier on the reciprocating part of the machine, is shown in Fig. 6. The carrier assembly shown holds eight flasks, supported in pairs by clamps which screw down firmly over the tops of the flasks as shown in Fig. 7. The clamp consists of two inverted cups, each containing a sponge rubber disk, mounted on a plate. The cups cover the stoppers and upper necks of the flasks and serve as a safety guard.

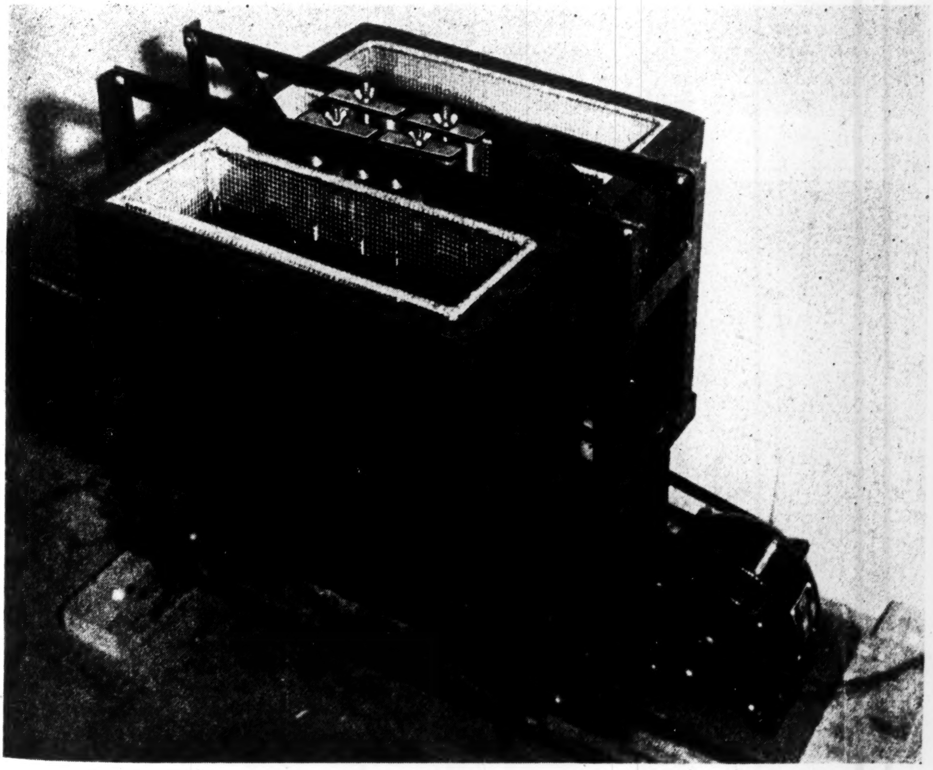

FIG. 5.—Shaking Machine with Stationary Ice-Water Bath.

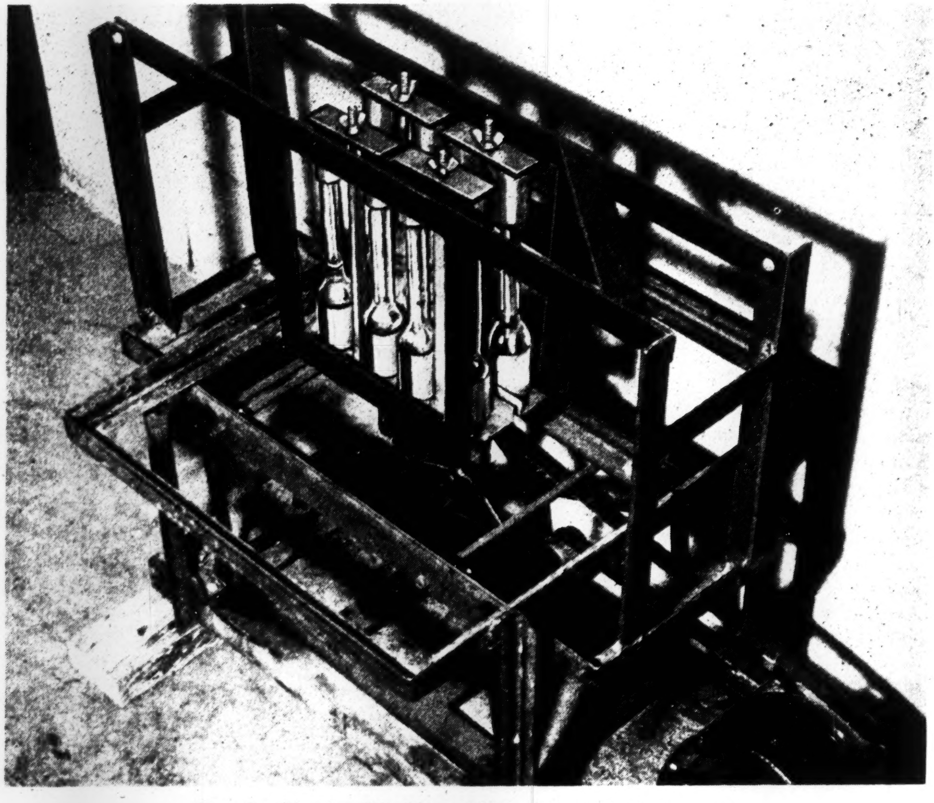

FIG. 6.—Shaking Machine with Ice-Water Bath Removed.

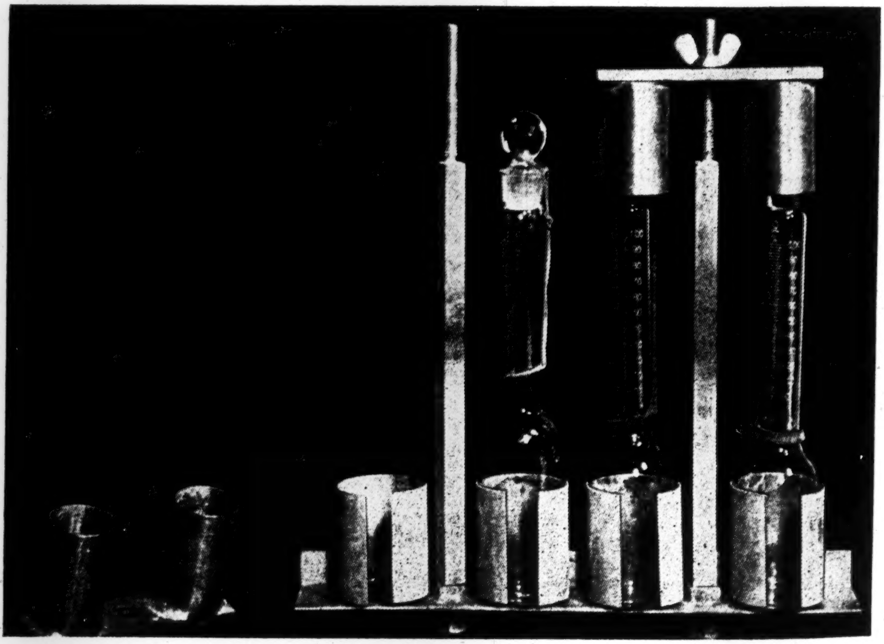

FIG. 7.—Sulfonation Flask Holder and Clamp for Shaking Machine.

REPORT OF COMMITTEE D-3

ON

GASEOUS FUELS*

Committee D-3 on Gaseous Fuels and its seven subcommittees held a joint meeting in New York, N. Y., on October 4, 1944, followed by a meeting of the Advisory Committee.

Much progress has been made by the subcommittees, in their various assignments despite difficulties resulting from wartime conditions. The principal activities of the subcommittees for the past year are summarized below:

Subcommittee I on Collection of Gaseous Samples (S. J. Modzikowski, chairman).—Reorganization of the work of this group was accomplished at a meeting held in June, 1944. The preparation of separate sampling methods for natural, manufactured, and liquefied petroleum gases is now in progress. Draft of a method for sampling liquefied petroleum gases is being completed.

Subcommittee III on Determination of Calorific Value of Gaseous Fuels (R. B. Harper, chairman).—Following much preliminary work a draft of a Proposed Tentative Method of Test for Calorific Value of Gaseous Fuels by the Water Flow Calorimeter was completed some months ago and copies distributed for review and criticism. It is proposed to embody the comments received in a final draft to be distributed in the near future to members of the subcommittee for their approval.

Subcommittee IV on Determination of Specific Gravity and Density of Gaseous Fuels (E. F. Schmidt, chairman).—Publication of an abstract of previous tests on specific gravity instruments by the National Bureau of Standards has created considerable interest and led to a number of requests for the complete report. Its publication is now under consideration and it is hoped that this may be completed at an early date. The subcommittee is also hopeful that additional tests on instruments included in the former investigation may be conducted by the National Bureau of Standards.

Subcommittee V on Determination of Special Constituents of Gaseous Fuels (E. F. Pohlmann, chairman).—Studies on determination of sulfur content of gaseous fuels are under way at the Institute of Gas Technology. When proposed methods are prepared it is planned to distribute them to various laboratories for actual trial under practical conditions before requesting their consideration by the subcommittee. By so doing it is believed that the development of final methods will be much facilitated.

Subcommittee VI on Determination of Water Vapor Content of Gaseous Fuels (A. W. Gauger, chairman).—Most of the studies so far performed by this group have been carried out at The Pennsylvania State College. Present plans call for securing an infrared spectroscope now on the market which is believed to be well adapted for referee purposes. It is also proposed to construct, for further study, a model of an instrument recently developed by one of the members of the committee

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

Subcommittee VII on Complete Analysis or Chemical Composition of Gaseous Fuels (Martin Shepherd, chairman).—Cooperative analysis of standard gas samples is well advanced and a preliminary report is in preparation. This will include results of various analyses performed by various members of the subcommittee and cooperating laboratories.

This report has been submitted to letter ballot of the committee which consists of 31 members; 30 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. W. GAUGER,
Chairman.

R. M. CONNER,
Secretary.

REPORT OF COMMITTEE D-5
ON
COAL AND COKE*

Committee D-5 on Coal and Coke held no meetings during the past year. The work of its subcommittees was curtailed because of the war activities of many members.

During the year J. F. Kohout replaced L. C. McCabe, resigned, on the committee as the representative of the Corps of Engineers of the U. S. War Department; S. S. Tomkins replaced C. A. Lunn, resigned, as the representative of the Consolidated Edison Co. of New York, Inc.; and A. W. Gauger was appointed chairman of Subcommittee II on Nomenclature and Definitions, replacing H. C. Porter, deceased.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Testing (W. A. Selvig, chairman) has recommended a change in the tolerances between duplicate determinations of volatile matter for anthracite, low-temperature coke, and subbituminous coal for publication as a tentative revision of the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 44),[1] referred to later in this report, to permit more liberal tolerances for these fuels. This recommendation is based on the experience of different laboratories in analyzing these fuels and supporting data are given in a paper on "Precision of the Volatile Matter Determination for Anthracite, Low-Temperature Coke, and Subbituminous Coal,"[2] by W. A. Selvig.

Subcommittee XI on Coal Friability (R. E. Gilmore, chairman) has recommended that the Tentative Method of Tumbler Test for Coal (D 441 - 37 T) be adopted as standard with minor revisions. The Tentative Method of Drop Shatter Test for Coal (D 440 - 37 T) is on the recommendation of the subcommittee, being continued as tentative as this test will probably require considerable revision.

I. TENTATIVE REVISION OF STANDARD

The committee recommends for publication as tentative the following revision in the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 44):[3]

Section 43.—In this section on reproducibility of results, change the requirements for maximum permissible differences between two or more determinations of volatile matter from its present form: namely,

Volatile Matter	Permissible Differences	
	Same Laboratory	Different Laboratories
Anthracite and Coke	0.2	0.4
Semianthracite, Bituminous Coal, Subbituminous Coal, and Chars	0.5	1.0
Lignite and Peat	1.0	2.0

to read as follows:

Volatile Matter	Permissible Differences	
	Same Laboratory	Different Laboratories
High-temperature Coke	0.2	0.4
Anthracite	0.3	0.6
Semianthracite, Bituminous Coal, Low-temperature Coke, and Chars	0.5	1.0
Subbituminous Coal	0.7	1.4
Lignite and Peat	1.0	2.0

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*Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] See Editorial Note, p. 256.

[2] *Report of Investigations 3739*, U. S. Bureau of Mines (1943).

[3] 1944 Book of A.S.T.M. Standards, Part III.

This recommendation has been submitted to letter ballot of the committee which consists of 53 members; 45 members returned their ballots, all of whom have voted affirmatively.

II. ADOPTION OF TENTATIVE METHOD AS STANDARD

The committee recommends that the Tentative Method of Tumbler Test for Coal (D 441 - 37 T)[3] be approved for reference to letter ballot of the Society for adoption as standard with the following revisions:

Section 1.—In the first and third sentences, change the word "lump" to read "sized," and add an additional sentence after the second sentence to read as follows: "The test is serviceable for ascertaining the similarity of coals in respect to friability rather than for determining values within narrow limits in order to emphasize their dissimilarity."

Section 4 (a).—In the second sentence, change the word "lumps" where it first occurs to read "pieces of coal" and change "1.06 to 1.50-in. lumps" to read "1.06 to 1.50-in. size." In the remainder of Paragraph (*a*) change the word "lumps" wherever it occurs to read "pieces."

Section 6.—In the fourth sentence of the Note following this section, change the word "lumps" to read "pieces."

This recommendation has been submitted to letter ballot of the committee which consists of 53 members; 45 members returned their ballots, of whom 41 have voted affirmatively, 0 negatively, and 4 members marked their ballots "not voting."

III. TENTATIVE METHODS CONTINUED AS TENTATIVE

The committee recommends that the following methods of test that have stood for two years or longer without revision be continued as tentative, as revisions may be desirable before they are adopted as standard:

Tentative Methods of:

Test for Grindability of Coal by the Ball-Mill Method (D 408 - 37 T),
Test for Grindability of Coal by the Hardgrove-Machine Method (D 409 - 37 T),
Drop Shatter Test for Coal (D 440 - 37 T),
Sampling Coals Classed According to Ash Content (D 492 - 43 T), and
Test for Free-Swelling Index of Coal (D 720 - 43 T).

This report has been submitted to letter ballot of the committee which consists of 53 members; 45 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. C. FIELDNER,
Chairman.

W. A. SELVIG,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 8, a proposed tentative revision of the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 44) referred to in the report was submitted by Committee D-5 and accepted by the Administrative Committee on Standards on June 27, 1945. The tentative revision appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

REPORT OF COMMITTEE D-6

ON

PAPER AND PAPER PRODUCTS*

Committee D-6 on Paper and Paper Products held one meeting during the year, on June 27, 1944, in New York, N.Y.

Cooperative relations are being continued between Committee D-6 and other A.S.T.M. committees, as well as other standardizing bodies.

During the year the Society was invited to appoint a representative to serve on the Testing Division Advisory Committee of the Technical Association of the Pulp and Paper Industry. L. S. Reid of Committee D-6 was appointed as this representative.

At the present time, Committee D-6 consists of 68 members, of whom 56 are voting members; 25 are classified as producers, 19 as consumers, 19 as general interest members, and 5 as consulting members.

I. New Tentative Methods

The committee recommends that the following new methods, prepared by Subcommittee I, be accepted for publication as tentative, as appended hereto:[1]

Tentative Methods of Test for:

Ply Adhesion of Paper and Vulcanized Fibre,
Absorption by Bibulous Papers of Water and Writing Ink,
Degree of Wet Curl of Paper,
Water Vapor Permeability of Sheet Materials at Elevated Temperature and Humidity,
Edge Tearing Strength of Paper,
Wet Tensile Breaking Strength of Paper and Paper Products, and
Tensile Breaking Strength of Paper and Paper Products.

II. Adoption of Tentative Methods as Standard

The committee recommends that the following five tentative methods[2] be approved without change for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of:

Turpentine Test for Grease Resistance of Paper (D 722 - 43 T),
Test for Degree of Staining of Paper by Alkalies (D 723 - 43 T),
Test for Surface Wettability of Paper (Angle-of-Contact Method) (D 724 - 43 T),
Test for Wire and Felt Sides of Paper (D 725 - 43 T), and
Test for Kerosine Number of Roofing and Flooring Felts by the Vacuum Method (D 727 - 43 T).

The remaining tentative methods under the jurisdiction of Committee D-6 although requiring no revision, are recommended for continuation as tentative in their present form.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 56 voting members; 40 members returned their ballots with the results shown in Table I.

Activities of Subcommittees

Subcommittee I on Paper Testing Methods (W. R. Willets, chairman) has held two meetings during the year. The subcommittee has been active in developing new methods of test and has also continued its critical study of various methods of test of paper and paper products that have been adopted by other agencies, for example, those of the Technical Association of the Pulp and Paper Industry. The subcommittee prepared seven new methods of test which are being recommended for publication as tentative, as mentioned earlier in this report.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] These methods were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[2] 1944 Book of A.S.T.M. Standards Part III.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE METHODS			
Test for Ply Adhesion of Paper and Vulcanized Fiber	32	0	8
Test for Absorption by Bibulous Papers of Water and Writing Ink	32	0	8
Test for Degree of Wet Curl of Paper	35	0	5
Test for Water Vapor Permeability of Sheet Materials at Elevated Temperature and Humidity	31	3	6
Test for Edge Tearing Strength of Paper	36	0	4
Test for Wet Tensile Breaking Strength of Paper and Paper Products	36	0	4
Test for Tensile Breaking Strength of Paper and Paper Products	37	0	3
II. ADOPTION OF TENTATIVE METHODS AS STANDARDS			
Turpentine Test for Grease Resistance of Paper (D 722 - 43 T)	32	0	8
Test for Degree of Staining of Paper by Alkalies (D 723 - 43 T)	33	0	7
Test for Surface Wettability of Paper (Angle-of-Contact Method) (D 724 - 43 T)	30	0	10
Test for Wire and Felt Sides of Paper (D 725 - 43 T)	34	0	6
Test for Kerosine Number of Roofing and Flooring Felts by the Vacuum Method (D 727 - 43 T)	30	0	10

The five tentative methods being recommended for adoption as standard are also under the jurisdiction of this subcommittee.

Methods on the following subjects are being given consideration by Subcommittee I:

Stretch of Paper and Paperboard,
Test for Sulfates and Chlorides in Paper,
Creasing of Paper for Water Vapor Permeability Test,
Erasing Properties of Paper,
Fiber Composition of Paper,
Gloss,
Lint on Paper, and
Stiffness of Paper.

In addition to the above subjects, studies are being made which may lead to proposed revisions in the Tentative Method of Qualitative Examination of Mineral Filler and Mineral Coating of Paper (D 686 - 43 T) and the Tentative Method of Test for Resistance of Paper to Passage of Air (D 726 - 43 T).

Subcommittee I also has developed a Method of Test for Smoothness of Paper. This is still under consideration and is therefore, not being submitted for publication as tentative, but is included as an Appendix to this report for further information and criticism.

Subcommittee II on Significance of Test Methods (C. C. Heritage, chairman) prepared the monograph on "Paper and Paperboard, Characteristics, Nomenclature, and Significance of Tests" which was published during the year. It includes a discussion of paper manufacture and the nature of paper from the chemical standpoint and as a complex structure; also the action of water on paper and its significance, and a detailed discussion of the properties of various classes of paper and paperboard. The individual tests applied to paper and paperboard and their significance are also discussed at considerable length in this publication. Also included is an index and a very complete cross-reference list of A.S.T.M. and T.A.P.P.I. methods of tests.

Subcommittee IV on Fiberboard and Fiberboard Containers (R. L. Beach, chairman) has held no meetings during the year. However, it has been active and a task group has been appointed to work on the possible revision of the Tentative Method of Test for Puncture and Stiffness of Paperboard, Corrugated and Solid Fiberboard (D 781 – 44 T).[2]

In addition to this, test procedures for the following are under consideration:

Uncombined Board:

- Ring Tests,
- Tension Tests,
- Thickness Tests,
- Tape Tests.

Combined Boards:

- Beam Tests,
- Adhesion Tests,
- Surface Moisture Resistance Tests,
- Score Line Tests,
- Scuffing Tests,
- Immersion Tests, and
- Test for Delamination of Plies.

Set-Up Containers:

- Test for Flap Closures.

The Advisory Committee held a meeting on June 27, 1944, at which time recommendations were made to set up a group to study the advisability of forming a new subcommittee to handle public relations and another group to study a possible revision of the By-laws. It was also recommended that the activities of Subcommittee II be expanded to include the possibility of developing material specifications for specific papers.

During the year, the second issue of the compilation of "A.S.T.M. Standards on Paper and Paper Products," prepared by Committee D-6, was published. This compilation has been enlarged and now contains 42 methods of test, 39 of which were prepared by the subcommittees of Committee D-6, and 7 specifications on paper products which were prepared by other A.S.T.M. committees.

This report has been submitted to letter ballot of the committee, which consists of 56 voting members; 40 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. S. REID,
Chairman.

G. H. HARNDEN,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 8, seven proposed tentatives, which are also referred to in the report, were submitted by Committee D-6 and accepted by the Administrative Committee on Standards on June 27, 1945. The new tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

APPENDIX

PROPOSED METHODS OF TEST FOR SMOOTHNESS OF PAPER[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. These methods of test for smoothness of paper are suitable for all grades of paper used for printing purposes except made-up corrugated board. Three procedures each using different types of apparatus are included. No constant relationship exists between test values obtained by these several methods. The use of any particular one will be governed by the specifications of the purchase order.

METHOD A. BEKK SMOOTHNESS TESTER

Apparatus

2. The apparatus shall consist of the following:

(*a*) *Bekk Smoothness Tester.*—The Bekk smoothness tester shall have the following features:

(*1*) A circular plane surface having an effective area of 10 sq. cm., and a small circular aperture in the center.

(*2*) A means of applying the circular plane against the paper, with a pressure of 1 kg. per sq. cm., and drawing room air between the paper and the plane surface with a vacuum of 380 to 360 mm. of mercury.

(*3*) A means of passing a known volume (10 ml.) of air, controlled by the size of the air chamber, between the paper surface and the plane surface.

(*4*) A means of measuring the volume and rate of change in vacuum from 380 to 360 mm. in passing the air between the two surfaces.

(*b*) *Stop Watch.*

Adjustment and Calibration of Apparatus

3. (*a*) Check the instrument frequently for leakage. By means of the vacuum pump, pull the mercury level to 500 mm., turn the stopcock counterclockwise to the "*O*" position, and let the instrument remain in this state for at least 5 hr. If the drop in the mercury column is over 5 mm., tighten the gaskets. If air leakage continues, remove the stopcocks and the regulating valve pin, clean, and apply a thin film of stopcock grease to the polished surfaces. Make certain that the nut holding the block in place is tight.

(*b*) It is particularly important that the capillary be kept clean. A jerking movement of the mercury column or adherence of the mercury to the capillary sides is an indication that the capillary is dirty. Carefully remove the capillary and clean by washing it alternately with nitric acid and a solution of potassium bichromate in sulfuric acid (sp. gr. 1.84). Remove all the cleaning solution from the capillary with distilled water and then rinse, first with alcohol and then with ether. Dry the tube thoroughly by letting it stand in a warm room or by blowing filtered warm air through it.

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[1] These proposed methods are under the jurisdiction of the A.S.T.M. Committee D-6 on Paper and Paper Products. Published as information, June, 1945.

Before inserting the capillary, it is recommended that a layer approximately 2 mm. in height of pure benzyl salicylate be poured on top of the mercury. This insures steadier movement of the mercury column.

(*c*) Whenever the instrument is not being used, protect the polished surface block with the dust cap. Keep the surface of this block and the rubber pad clean at all times. Handle the rubber pad by the edges to prevent grease from finger tips accumulating on surface of the pad. If dirt and grease from handling have accumulated on the surface of the pad, it may be cleaned with carbon tetrachloride. When a pad becomes hard, discard it.

Test Specimen

4. The test specimens not less than 2 by 2 in. shall be cut in such a manner as to represent accurately the sample which has been selected in accordance with the Standard Method of Sampling Paper and Paper Products (A.S.T.M. Designation: D 585)[2] and conditioned in accordance with the Standard Method of Conditioning Paper and Paper Products for Testing (A.S.T.M. Designation: D 685).[2] Test specimens shall be clean and free from abnormalities such as watermarks, creases, and wrinkles. Mark the wire and the felt sides of the paper.

Procedure

5. (*a*) Perform the smoothness measurements in an atmosphere conditioned in accordance with A.S.T.M. Method D 685. Set the stopcock of the tester to position "*P*." With gentle strokes of the vacuum pump plunger, pull the mercury column slightly above 380 mm., then turn the stopcock counter-clockwise to position "*O*."

(*b*) Place the side of the specimen to be tested on the polished glass disk, then lay the square of soft gum rubber on the paper and on top of this center the metal pressure disk. Bring the lever down to a horizontal position so that the leveling screw rests on the bore in the center of the metal disk. With the aid of the spirit level, and by means of the leveling screw, maintain the pressure bar in a level position throughout the test. Turn the stopcock counter-clockwise to position "*M*" and with the fine regulating vent at the base of the air chamber, by a gentle pulling-turning motion, permit the mercury column to drop to approximately 380 mm. Just before the mercury column reaches 380 mm., close the fine adjustment vent with a firm pushing-turning motion, and at the instant the 380-mm. mark is reached, start the stop watch, noting the time required for the mercury column to drop from 380 to 360 mm. This figure represents the time necessary for 10 ml. of air to pass between the plane surface and that of the test specimen. This is a numerical measure of the smoothness of the sample. Before removing the paper, turn the stopcock clockwise back to the "*O*" position. If the time required for the 20 mm. drop is over 300 sec., turn the stopcock clockwise to the $\frac{1}{10}$ position and multiply the observed time, for the 20 mm. drop, by 10. Test at least five specimens for the wire side and at least five specimens for the felt side of the sample. Use separate specimens for each test since the pressure on the test specimen compresses the fibers in the sample.

Report

6. The report shall include the following:

(*1*) Time in seconds for the wire side of the specimens, tested,

(*2*) The time in seconds for the felt side of the specimens, tested, and

(*3*) Name of the apparatus used.

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[2] 1944 Book of A.S.T.M. Standards, Part III.

METHOD B. GURLEY-HILL S-P-S TESTER

Apparatus

7. The apparatus shall consist of the following:

(*a*) *Gurley-Hill S-P-S Tester.*—The Gurley-Hill S-P-S (Softness, Porosity, Smoothness) tester shall have the following features:

(*1*) A pair of clamping plates having an annular contact area of 1 sq. in. The contact surfaces shall be finished flat within 0.0001 in. The outside diameter of the contact ring shall be approximately 1.593 in., and the inside diameter shall be approximately 1.125 in. The upper plate shall be fixed to the outlet of an air tube, and the lower plate shall be supported at its center upon a rounded-head pin. The lower plate shall be arranged to press against the upper plate with a pressure of 3 lb. when supported by a deadweight lever arm. The lever arm shall be raised and lowered by a cam, for convenience in inserting, clamping, and removing test specimens.

(*2*) Air pressure for the test shall be provided by an inner cylinder having a closed top, sliding freely in an outer cylinder which is partly filled with oil (Note) having a viscosity of 60 to 70 sec. Saybolt Universal at 100 F. and a flash point of not less than 275 F. The air shall be conducted to the clamping plates through a tube extending above the surface of the oil in the outer cylinder.

(*3*) The outer cylinder shall be approximately 10 in. in height, and shall have an internal diameter of 3.25 in. It shall be equipped with four slender bars, each 7.5 in. in length, 0.12 in. in width, and approximately 0.06 in. in thickness, mounted vertically and equidistantly on the inner surface of the outer cylinder, to act as guide tracks for the movable cylinder.

(*4*) The movable inner cylinder shall be graduated in units of 50 ml. and shall have a total range of 350 ml. It shall be 10 in. in height, and shall have an external diameter of 3.00 in. and an internal diameter of 2.90 in. It shall weigh 568 ± 0.5 g. producing an air pressure equal to 4.89 in. of water.

(*5*) A support shall be provided on the outer cylinder to hold the inner cylinder in a raised position prior to making a test.

(*b*) *Punch.*—A punch for making a hole through the specimens.

(*c*) *Stop Watch.*—A stop watch, or automatic timing device.

NOTE.—A light spindle oil is suitable for this purpose. Oil is used in preference to water because it does not permit electrolysis of the aluminum inner cylinder, and because it does not affect the moisture content of the specimen. The oil should not contain any essential oil or other easily volatile oil, and for that reason a minimum flash test is specified.

Calibration of Apparatus

8. The apparatus shall be tested for instrument air leakage by clamping the plates in the normal manner after their contact surfaces have been thoroughly cleaned. The inner cylinder shall then be released so that it floats. The air leakage shall not exceed 50 ml. in 4 hr.

Test Specimen

9. (*a*) The test specimens shall be cut from the original sample obtained in accordance with the Standard Method of Sampling Paper and Paper Products (A.S.T.M. Designation: D 585)[2] and conditioned in accordance with the Standard Method of Conditioning Paper and Paper Products for Testing (A.S.T.M. Designation: D 685).[2]

(*b*) The test specimens may consist of a single sheet folded (Note 1) so as to make a pad of eight thicknesses (Note 2), not less than 2 by 2 in. nor more than 10 by 10 in.; or, a larger area of paper may be included in the test by using eight separate sheets taken from different portions of the roll or skid. In the latter case, the sheets shall be interleaved so that the felt and wire sides are placed in contact with each other.

NOTE 1.—The use of a single folded sheet is recommended only in the case of paper which can be sharply creased. Thick or stiff paper will tend to hold the individual sheets apart, due to the resistance to creasing. Likewise, the use of specimens of a size over 10 by 10 in. will overhang the lower test plate and be partly supported by the table or bench on which the instrument is placed. Samples of unusual weight will decrease the actual clamping pressure.

NOTE 2.—In the case of extremely low or high smoothnesses, it may be convenient to use a smaller or larger number of thicknesses in the pad, but in the usual range of paper, eight ply will provide convenient readings.

Procedure

10. (*a*) Test not less than five sets of conditioned test specimens in the standard atmosphere prescribed in A.S.T.M. Method D 685.

(*b*) Place the apparatus on a level surface so that the cylinders are vertical. Fill the outer cylinder with oil to a depth of approximately 5 in., as indicated by a ring marked on the inner surface of the cylinder.

(*c*) Fold, or interleave, the test specimen as described in Section 9(*b*). Insert it in the punch in the base of the apparatus, and punch a hole through it.

(*d*) Raise the inner cylinder until it rests on the support. Insert the punched specimen between the clamping plates. Raise the lower clamping plate by means of the capstan screw until the clamping action depresses the lower plate sufficiently to cause the lever arm to rise free of its cam. Release the lever arm by means of the handle which actuates the lifting cam. The specimen is now clamped for test under a deadweight of 3 lb.

(*e*) Lower the inner cylinder gently until it floats in the oil.

(*f*) When a steady downward movement has been reached, measure the interval of time by a stop watch or other timing device, for any two graduations to pass the rim of the outer cylinder, providing that not less than 5 sec. elapse between the passing of any two consecutive graduations.

(*g*) Precautions should be taken to avoid subjecting the apparatus to vibration as this would increase the rate of air displacement.

Report

11. The report shall include the following:

(*1*) Number of seconds required for the displacement of 50 ml. of air, or Gurley-Hill S-P-S seconds,

(*2*) Area of the test specimen over which the air was displaced, and

(*3*) Name of the apparatus used.

METHOD C. WILLIAMS SMOOTHNESS TESTER

Apparatus

12. The apparatus shall consist of the following:

(*a*) *Williams Smoothness Tester.*—The Williams smoothness tester shall have the following features:

(*1*) A specimen holder comprised of an upper and lower jaw with soft-rubber facings, the lower jaw being an annular ring 2-in. in outside diameter and with a hole in the center 1 in. in diameter.

(*2*) A means of applying a known pressure to this area of 30 psi.

(3) A means of passing a known volume (25 ml.) of air, between the two surfaces of the specimen to be tested. The air supply is obtained by forcing a cylinder, open at lower end, down to a fixed step into a reservoir of mercury. The enclosed air is conducted to the specimen by means of a pipe entering the movable cylinder. The movable cylinder is provided with a friction ring which holds it in position when it has been forced down to its lowest point.

(*b*) *Stop Clock.*—An automatic electric stop clock to measure the rate of air passing between the two surfaces of the specimen. The depression of the movable tube not only measures a definite quantity of air at a definite pressure, but also elevates the surface of the mercury in the surrounding cistern up to and beyond an electric contact point. The mercury upon reaching the contact point starts the electric stop clock. As the air pressure is relieved, the level of the mercury gradually falls until it comes below the contact point which breaks the circuit, stopping the electric clock. The timing of the test is automatic and independent of personal observation.

Adjustment and Calibration of Apparatus

13. (*a*) This apparatus is provided with a standard stainless steel plate having an accurate and fixed rate of air escapement.

(*b*) To standardize the apparatus, it is only necessary to repeat the test for paper, using the standard stainless steel test plate instead of the paper specimen.

(*c*) An average of ten tests showing both maximum and minimum readings should be taken for the standardization test.

Test Specimen

14. (*a*) The sample of paper shall be selected in accordance with the Standard Method of Sampling Paper and Paper Products (A.S.T.M. Designation: D 585),[2] and conditioned in accordance with the Standard Method of Conditioning Paper and Paper Products for Testing (A.S.T.M. Designation: D 685).[2]

(*b*) The test specimens shall be cut from the sample and shall be clean and free from abnormalities such as watermarks, creases, and wrinkles. Any convenient size of specimen may be used and, as the clamping jaws are open in front, the folded specimen may be of any reasonable length or shape.

Procedure

15. (*a*) Raise the movable column to its highest point. See that the electric stop clock is set at zero. Insert the folded specimen perforated in the center, between the rubber-faced clamping plates. Screw down the clamp above the pressure gage until a pressure of 30 psi. is reached. Force down the movable column to the fixed stopping point. This operation starts the clock. The test requires no further attention as the clock automatically stops at the completion of the test.

(*b*) Other volumes of air may be used by merely raising or lowering the height of the electric contact point. The clamping pressure may also be varied as indicated upon the pressure gage by manipulation of the clamping screw directly above the gage.

(*c*) Several modifications of this method are possible under controlled conditions, to increase or decrease the reading range on different types of paper. For example, the use of a test specimen folded upon itself, doubles the tested area and therefore, represents a better average of the surface conditions of the sample. It also reduces the testing time to practically one-half. This method is recommended for smooth papers giving a smoothness reading of several hundred seconds. On the other hand, comparatively rough papers will give a comparatively short reading time of only a few seconds. In such cases, the reading time or scale may be increased by pressing one surface of the specimen only, against a plate-glass disk. In any event, in order to obtain comparable results, working conditions shall be uniform.

Report

16. The report shall include the following:

(*1*) Values for the wire side and the felt side of the test specimen in terms of the time in seconds required for the passing of 25 ml. of air under a pressure of 30 psi.

(*2*) Name of the apparatus used.

REPORT OF COMMITTEE D-7

ON

WOOD*

Committee D-7 on Wood held a well-attended meeting at New York, N. Y., on June 27, 1944, in conjunction with the Annual Meeting of the Society, and a meeting at Chicago, Ill., on April 11, 1945. It has been evident that there has been throughout the year an increasing interest in the activities of the committee.

Because of the development of new products and materials from wood, much consideration has been given to the reorganization of Committee D-7 to broaden its scope and functions, resulting in a change in the title of the committee from Committee D-7 on Timber to read Committee D-7 on Wood, and the broadening of the scope to include activities on a variety of new subjects and materials. Concurrent with these revisions has been the establishment of a revised subcommittee structure as follows:

- Subcommittee I on Specifications for Timber
- Subcommittee II on Laminated Timber
- Subcommittee III on Plywood
- Subcommittee IV on Wooden Paving Blocks
- Subcommittee V on Methods of Preservative Treatment of Timber
- Subcommittee VI on Timber Preservatives
- Subcommittee VIII on Modified Wood and Wood-Base Materials
- Subcommittee IX on Methods of Testing
- Subcommittee X on Nomenclature and Definitions
- Subcommittee XI on Moisture Content of Timber
- Subcommittee XII on Fire-Retardant Wood

Plans are under way to enlarge the membership of Committee D-7 in conformity with the broadened scope and diversity of its activities.

Recommendations Affecting Standards

The committee is submitting revisions[1] in the Tentative Methods of Testing Plywood, Veneer, and Other Wood and Wood-Base Materials (D 805 – 44 T).

This recommendation has been submitted to letter ballot of the committee which consists of 32 members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. Revision of Tentative Testing Veneer, Plywood, and Other Wood and Wood-Base Materials (D 805 - 44 T).......	28	0	0

Activities of Subcommittees

Subcommittee I on Specifications for Timber (L. J. Markwardt, chairman).—No changes have been made or recommended in the current Standard Specifications for Structural Wood Joist and Plank, Beams and Stringers, and Posts and Timbers (D 245 – 37), although these specifications will be considered for revision in the post-war period. Such revisions as may be contemplated are intimately associated with the question of increased working stresses which are under close analysis at the present time. Further revisions will embody also consideration of grade requirements for timbers subjected to tension stresses as in the lower chord of truss members.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] These revised methods were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part II.

Subcommittee V on Methods of Preservative Treatment of Timber (A. L. Kuehn, chairman).—Suggestions are being requested regarding further work which the subcommittee should undertake on the preservative treatment of timber, and it is contemplated that considerable progress will be made during the coming year.

Subcommittee VI on Timber Preservatives (C. S. Reeve, chairman).—Subcommittee VI has been enlarged in order to be more representative of the industry and to be better prepared to consider the expanded field of new preservatives and methods of testing. No immediate revisions are contemplated in the following standards which have stood for 6 years or more without revision:

Standard Methods of:[2]

Sampling and Testing Cresote (D 38 – 33),
Test for Coke Residue of Creosote (D 168 – 30),
Chemical Analysis of Zinc Chloride (D 199 – 27),
Test for Insoluble Matter in Creosote (D 367 – 33),
Test for Specific Gravity of Creosote (D 368 – 33),
Test for Specific Gravity, 38/15.5 C., of Creosote Fractions (D 369 – 33),
Test for Water in Creosote (D 370 – 33),
Specifications for Creosote (D 390 – 36), and
Volume and Specific Gravity Correction Tables for Creosote and Coal Tar (D 347 – 33).

Subcommittee IX on Methods of Testing (L. J. Markwardt, chairman).—This subcommittee prepared the Tentative Methods of Testing Veneer, Plywood, and Other Wood and Wood-Base Materials (D 805 – 44 T) which were accepted[3] by Committee E-10 on Standards on August 28, 1944, on the recommendation of Committee D-7 and appear in the 1944 Book of A.S.T.M. Standards, Part II, having first been published as information with the 1944 report of the committee. These tentative methods cover procedures for determining the following properties of veneer, plywood, and other wood and wood-base materials: compression, static bending, tension, Forest Products Laboratory panel shear, FPL plate shear, toughness, hardness, moisture content, and specific gravity.

Revisions are now being recommended in Tentative Methods D 805, which include some additional procedures for conducting plywood glue shear strength tests and moisture absorption tests.[4]

Under preparation during the year also has been a revision of the Standard Methods of Testing Small Clear Specimens of Timber (D 143 – 27). The revision will include modification and clarification of the sampling procedure, revision of the tension-parallel-to-grain test method, and enlargement to include some additional tests. It is hoped that the proposed revision can be submitted to the Society during the current year.

Subcommittee X on Nomenclature and Definitions (C. J. Hogue, chairman).—After careful consideration, the following definition of brashness has been prepared and is being considered for incorporation in the Standard Definitions of Terms Relating to Timber (D 9 – 30):[2]

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[2] 1944 Book of A.S.T.M. Standards, Part II.

[3] In submitting this recommendation to Committee E-10 on Standards, Committee D-7 reported results of the letter ballot vote as follows: Of a total membership of 30, 30 members returned their ballots, of whom 27 voted affirmatively, 0 negatively, and 3 members marked their ballots "not voting."

[4] See Editorial Note, p. 268.

Brashness.—A characteristic or a condition that causes some pieces of wood to be relatively low in shock resistance, and when broken in flexure, to fail abruptly without splintering and at comparatively small deflection.

Standard Definitions D 9 were reviewed by the subcommittee, and the following revised list of species names is being considered to replace the list appearing in the present definitions:

STANDARD NAMES FOR STRUCTURAL TIMBERS

Forest Service Standard Name	Botanical Name
Cedars	
Alaska Yellow Cedar	Chamaecyparis nootkatensis
Atlantic White Cedar	Chamaecyparis thyoides
Northern White Cedar	Thuja occidentalis
Port Orford White Cedar	Chamaecyparis lawsoniana
Western Red Cedar	Thuja plicata
Cypress	
Bald Cypress (coast type)	Taxodium distichum
Bald Cypress (inland type)	Taxodium distichum
Douglas Fir	
Douglas Fir (coast type)	Pseudotsuga taxifolia
Douglas Fir (intermountain type)	Pseudotsuga taxifolia
Douglas Fir (Rocky Mountain type)	Pseudotsuga taxifolia
The True Firs	
Balsam Fir	Abies balsamea
Commercial White Fir:	
California Red Fir	Abies magnifica
Grand Fir	Abies grandis
Noble Fir	Abies procera
Pacific Silver Fir	Abies amabilis
White Fir	Abies concolor
Hemlocks	
Carolina Hemlock	Tsuga caroliniana
Eastern Hemlock	Tsuga canadensis
Western Hemlock	Tsuga heterophylla
Larch (See also Tamarack)	
Western Larch	Larix occidentalis
Pines	
Eastern White Pine	Pinus strobus
Red Pine	Pinus resinosa
Ponderosa Pine	Pinus ponderosa
Sugar Pine	Pinus lambertiana
Western White Pine	Pinus monticola
Southern Pine:	
Longleaf Pine	Pinus palustris
Shortleaf Pine	Pinus echinata
Loblolly Pine	Pinus taeda
Pitch Pine	Pinus rigida
Pond Pine	Pinus rigida var. serotina
Slash Pine	Pinus caribaea
Redwood	
Redwood	Sequoia sempervirens
Spruces	
Black Spruce	Picea mariana
Blue Spruce	Picea pungens
Engelmann Spruce	Picea engelmanni
Red Spruce	Picea rubens
Sitka Spruce	Picea sitchensis
White Spruce	Picea canadensis
Tamarack (See also Larch)	
Tamarack	Larix laricina

Subcommittee XI on Moisture Content of Timber (M. E. Dunlap, chairman).—During the year the subcommittee had in preparation a proposed Tentative Method of Test for Moisture Content of Wood, which includes the use of various types of moisture meters that have been developed over the past several years. Since all moisture meters are subject to certain limitations and errors, the problem of establishing tentative methods of moisture determination has been complicated. A brief summary of the various methods of determining the moisture content of wood, which has been prepared by Mr. Dunlap, is appended to this report.

Subcommittee XII on Fire-Retardant Wood (W. H. Fulweiler, chairman).—This subcommittee has not met since its organization meeting in Chicago, Ill., in 1944, since there was not sufficient new information available to justify calling a meeting. The subcommittee has not been able to make as much progress as was anticipated on the study of the factors operating with the different types of tests, as outlined at its first meeting.

A considerable amount of information has been gathered, however, regarding the effect of moisture on the test results and the effect of methods of conditioning and methods for the determination of moisture content, and some study has been made in the chairman's laboratory on methods of controlling the amount of gas used in the test flame. None of this work, however, has progressed to where it is ready for a final report, but some recommendations have been made informally to the chairman for transmission to Committee C-5 on Fire Tests of Materials and Construction.

This report has been submitted to letter ballot of the committee which consists of 32 members; 28 members returned their ballots, of whom 27 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

HERMANN VON SCHRENK,
Chairman.

L. J. MARKWARDT,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-7 recommended to the Administrative Committee on Standards that the Tentative Methods of Testing Veneer, Plywood, and Other Wood and Wood-Base Materials (D 805 - 44 T) be revised as covered in the report. This recommendation was accepted by the Standards Committee on August 14, 1945, and the revised tentative appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part II, bearing the designation D 805 - 45 T.

APPENDIX

METHODS USED FOR THE MEASUREMENT OF THE MOISTURE CONTENT OF WOOD

By M. E. Dunlap[1]

Foreword to Appendix

Subcommittee XI on Moisture Content of Timber has under development tentative methods covering the various procedures for determining the moisture content of wood, with special consideration to the newer rapid procedures involving the use of electric meters.

Pending the development and completion of these tentative methods by the subcommittee, Mr. Dunlap as chairman has prepared a report summarizing the entire field of moisture content determination for wood, which is herewith presented as information as an appendix to the report of Committee D-7.

Hermann von Schrenk, *Chairman*
L. J. Markwardt, *Secretary*

Moisture content measurements are made in a variety of ways. For scientific, experimental, and more or less basic measurements, oven drying is depended upon where the wood contains little or no volatile oil that would be given off and measured as water when heated. Where volatile oils are present, either in the natural state or added by impregnation, a distillation method is used in which the wood sample is placed in a liquid such as xylol or kerosine and heated. The moisture is distilled from the sample and collected in a measuring tube. Electrical methods have come into extensive use in commercial control work in the manufacture and processing of lumber and make use of such electrical properties as electrical resistance, capacity, and radio-frequency power loss. Little used but nevertheless acceptable methods consist of the measurement of relative humidities which develop adjacent to a wood sample, or by a gas produced in a chemical reaction which removes water from the sample and causes a rise in pressure in an enclosure or a loss in weight by release of the gas. Paper treated with cobalt chloride indicates by color the approximate relative humidity conditions surrounding it.

Oven-Drying Method

Where a high degree of accuracy is required, the oven-drying test is used to determine moisture content when the wood contains no important amount of natural oils or is not impregnated with oils that would be lost upon oven drying. The method is carried out by heating the wood in a controlled-temperature oven near the boiling point of water (100 to 105 C.) until no further loss in weight occurs. The loss in moisture by weight, divided by the oven-dry weight and multiplied by 100 is the percentage of moisture in the wood represented by the sample. In some industries, notably the paper and pulp, moisture content is expressed on the basis of the original weight rather than the oven-dry weight. The test is relied upon in experimental work, in the control of seasoning processes, and in fabrication of wood products, although its use has not been as extensive for the latter since electrical meters have been in use. The test should be carried out with scales of appropriate accuracy and under controlled conditions to insure accurate results.

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[1] Chairman, Subcommittee XI on Moisture Content of Timber, of Committee D-7 on Wood.

DISTILLATION METHOD

When wood contains volatile oils, either natural or such injected ones as wood preservatives, and the moisture content is required to be known, it may be obtained by boiling a wood sample in a suitable liquid and collecting the water distilled from it in a measuring tube. This method is known as the xylol, miscible, or volatile-solvents method. The latter is not a good title because there is no solvent action so far as water is concerned. The fluid used merely transfers the heat to the wood samples and controls the temperature when operating at its boiling point.

In general, the process is carried out by heating a sample of wood, which is usually broken or split into rather small pieces and placed with the fluid to be used in a flask or kettle of a closed system. The water is then distilled from the wood, reduced to liquid water in a condenser, and collected in a receiving tube which is generally graduated for direct reading. Other products collecting as distillates are readily distinguished from the water in the receiving tube. The process can usually be carried out in about two hours or less if extreme accuracy is not demanded. The method requires special equipment and it can be set up in multiple so that the operator can make a number of tests simultaneously.

Some of the fluids used are highly inflammable, and special care must be taken while using them.

A modification of this method has been worked out wherein the samples are placed in an oven in tight containers with tubes connecting to condensers outside the oven which have calibrated receivers attached. A return tube is taken off above the receiver and taken back to the cylinder to induce circulation and vapor movement through the system toward the receiving tube. It is believed that no extensive use has been made of this method.

ELECTRICAL METHODS

Since 1930, electrical moisture meters have appeared on the market which are designed for the control of moisture in the manufacture of and processing of wood products. At least six manufacturers now make a variety of instruments based in principle on the electrical resistance of wood and the effect of wood and moisture on the electrical properties of a circuit when wood is placed in an electric field produced by the instrument. These instruments have been steadily improved and are now widely used in many of the wood-using industries.

Resistance Type:

The electrical resistance of wood varies inversely as the moisture content. In other words, as the moisture content of the wood decreases the resistance increases, and as the moisture content increases the resistance decreases. This enables one to evaluate the moisture content of wood by measuring the electrical resistance. The change in resistance with removal of the free water in wood is rather small, while removal of the hygroscopic water causes a great change. Hence, the evaluation of moisture content by measuring the resistance at moisture content values greater than the fiber-saturation point cannot be expected to be as accurate as the evaluation of moisture content at values less than the fiber-saturation point. The resistance of wood, however, becomes so great at values less than about 5 per cent moisture content that it is impractical to attempt the evaluation of moisture content by resistance methods with the ordinary portable apparatus.

The density of wood does not greatly affect the resistance of the wood, and errors resulting from variation in density are not important. There are, however, inherent differences in the specific resistance between species. Fortunately, reasonably accurate corrections can be made rather easily for species variations, and makers of the resistance type of moisture meters usually furnish correction data with their instruments.

Electrical contact is generally made by driving needle points into the wood so that the flow of current is parallel to the grain. The points are usually mounted in a block of insulating material and arranged so that they can be readily driven into the wood and withdrawn again after testing. Contact may also be made by clamping surface plates to opposite faces of the wood. The latter method is applicable to veneers, plywood, or solid wood known to be uniform in moisture content.

A study of moisture gradients in drying boards and planks has shown that, after the entire piece has passed the fiber-saturation point, the moisture content in a plane located at one fifth of the thickness of the material from its surface is usually very near the average moisture content of the piece. When a needle-point type of electrode is used in wood containing a drying gradient, the moisture meter indicates the moisture content at or near the points of the needles since the wood becomes a better conductor as the moisture content increases. It is thus possible to estimate the average moisture content by driving the needles to a depth of one fifth the thickness of the piece. Further, it is possible by driving electrodes to any desired depth to evaluate the moisture content at that particular distance from the surface as long as a drying gradient is present.

Failure to consider the moisture gradient may result in serious error in using the needle-point type of resistance moisture meter. Any uneven moisture distribution may be an important source of error. Thus the condition of the surface of the lumber often plays an important part in readings. During periods of high relative humidity, and particularly during foggy weather, the surface of the wood attains a high moisture content and may even be damp, thereby causing undue errors in the moisture-meter readings. Under such conditions, samples should be taken indoors and allowed to dry off before measurements are made.

The temperature of the wood must also be considered in readings of moisture content made with a resistance type of moisture meter, since the resistance of the wood increases with a falling temperature and decreases with a rising temperature. As with variations between species, reasonably accurate corrections for temperature may be easily made, and makers usually provide correction data with their instruments. In extreme cases, the temperature-correction factor may be as much as 5 or 6 per cent.

Electronic tubes have made it possible to include moisture contents of from 5 to 120 per cent in a single instrument, although most of the instruments available cover a range of from 7 or 8 per cent to 24 or 25 per cent moisture content.

The vacuum-tube voltmeter circuit serves as a basis for most of the resistance-type meters available to woodworkers. Two pairs of needles are driven into the wood, and the resistance between them is measured by comparing it to a known resistance or by connecting it directly into the grid circuit of the meter so that a definite amount of current flows in the plate circuit. In one instance, the plate voltage is increased until a neon tube is discharged. The setting of the dial indicates the moisture content directly. Another type, no longer available, indicated the moisture content by comparing the frequency of the breakdown of a neon tube in a circuit comprising a battery of above 180 v. and a resistance and a variable capacitor. By introducing different capacitors into the circuit, a measurement of resistance and moisture content could be obtained. A German instrument uses a neon tube as an indicator, a set of four capacitors, and a 500-v. hand generator. The number of turns required to build up the voltage potential to the breakdown voltage of the neon tube is used as an indication of the moisture content of the wood. The greater the leakage of current through the wood becomes, the fewer turns of the generator it will take to reach the breakdown voltage. This instrument was available in the United States prior to the war. A Swiss instrument consists of a hand generator, a capacitor, and an electrostatic voltmeter which draws no current. The voltage is built up in the capacitor to a definite amount, whereupon the generator is completely disconnected and the time required for the capacitor to discharge through the contact points driven into the wood is taken as an indication of the resistance of the wood and its moisture content.

Capacity Type:

The effect of wood as a dielectric in a condenser depends upon the amount of moisture in the wood. Therefore, the moisture content may be evaluated by the effect of wood and moisture on the electrical properties of a condenser. Temperature effects are so small as to be negligible for ordinary use, and there are no known errors introduced into readings by variations in properties inherent among different species except specific gravity. Capacity is directly proportional to dielectric constant, and therefore is a function of specific gravity. The specific gravity cannot be determined quickly enough by any method now available and hence it is present practice to assume the specific gravity of the individual piece when dry to be the same as the average for the species and to calibrate the moisture meter accordingly. Each reading on a meter so calibrated, therefore, carries an error proportional to the actual error in the assumed specific gravity of the piece. Since the readings are affected greatly by the specific gravity, only in running material of extremely uniform specific gravity can the individual readings be depended upon to give reliable moisture content values. Averages of a number of readings, however, are more reliable because they include a number of samples varying in density.

Several specific forms of condenser plates have been developed for obtaining measurements on wood. One form consists of two suitably insulated plates that are placed on opposite faces of the piece under test. In another form, two or more plates are assembled in the shape of a flat, circular disk several inches in diameter; in use, this assembly of plates is pressed against one surface of the piece under test.

Meters using condensers with plates

on opposite sides of the piece under test evaluate the total quantity of water in the wood irrespective of the moisture gradient, and the readings, therefore, are inherently true averages. Moisture gradients may well affect the readings of meters using condenser plates on only one side of the piece under test. It is not, however, feasible actually to determine moisture gradients or to measure the moisture content at various depths with any capacity meter.

The condition of the surface of the lumber also affects the readings of the capacity-type moisture meters. Smooth surfaces permit better contact with the condenser plates and accordingly give higher readings than rough surfaces. From the statements of the preceding paragraph, it follows that excessive surface moisture of lumber, such as is found during foggy or very damp weather, may have a serious effect on the readings taken with meters using condenser plates on one side of the piece.

Radio-Frequency Power-Loss Type:

Power absorbed by wood from a high-frequency alternating electric field is proportional to the product of the dielectric constant and the power factor of the wood. Both power factor and dielectric constant depend upon the amount of moisture in the wood. The exact effect of such factors as temperature, wood structure, resins, and soluble extractives on radio-frequency power loss is not known but is probably small. Specific gravity effects the dielectric constant; its relation to the power factor is not well established. Power loss also varies with species.

The radio-frequency power-loss moisture meter available is accompanied by a calibration for a number of commercial species. If specific gravities occur that are different from the one used as a calibration basis, the moisture content determined by the radio-frequency power-loss meter contains an error proportional to this difference.

The electrodes of this meter are four quadrants assembled into a circular disk but insulated from each other by an air space. An electrode comprising a disk with a concentric ring separated by a dielectric material has also been used. To measure the moisture content of a sample of wood, the electrodes are pressed firmly against the wood surface. The power loss in the wood, converted to moisture content, is indicated by the position of the needle of a galvanometer. The instrument dial is provided with two scales, one carries values for Douglas-fir and the other is arbitrary. The moisture content of a certain species can be obtained from the calibration tables by reading the moisture content opposite the reading indicated on the arbitrary scale.

MOISTURE CONTENT INDICATION BY RELATIVE HUMIDITY MEASUREMENTS

Because of the relationship that exists between relative humidity and the moisture content of hygroscopic substances in more or less confined spaces, their moisture content may be estimated by measuring the relative humidity in contact with the material. An instrument known as the duff hygrometer was designed to measure the moisture content of duff and closely packed debris on the floor of the forest as an indication of fire danger. In this case the perforated spike containing a hygroscopic element is inserted in the litter and is left there continuously. The rattan element changes in moisture content and length as that of the material about it varies, and in this way the moisture content reading may be determined at any time or a continuous record made.

Another instrument working on the

same principle, known as the wood hygrometer, has been applied to wood. In this case a hole was drilled in the wood and the instrument inserted in such a way that communication with the outside atmosphere was entirely shut off. The moisture liberated from the surfaces of the drilled hole quickly humidifies the enclosed space to a degree dependent upon the moisture content of the wood. The moisture content of the wood is determined by the height of a mercury column, to which is attached a bulb of goldbeaters skin containing the mercury. The humidity in the enclosed space causes the goldbeaters skin to shrink or swell, producing a rise or fall of the mercury in the glass capillary tube. The instrument is calibrated directly in moisture content. It was never developed commercially because of shipping difficulties. Two instruments operating on the same principles as the wood hygrometer were produced in Germany. One was equipped with a spike about 5 or 6 in. long containing a hygroscopic element (probably hair) connected to a pointer of a dial.

Another instrument made use of a color-matching device. A narrow strip of paper treated with cobalt chloride was inserted in a deep drilled hole in the lumber. After a definite period of time the strip of paper was withdrawn from the wood into a glass receiving tube and the color compared to a set of color standards. The color of the treated paper changes from a deep blue at low moisture content to a moderately bright shade of pink at 18 or 20 per cent moisture content.

CHEMICAL METHODS

When calcium carbide and water vapor are combined, acetylene gas is formed. This property has been made use of for measuring the moisture content of hay rapidly. In one case the hay is placed in a tight receptacle together with a separate container containing calcium carbide. After the vessel is closed the calcium carbide is released and the water in the material combines with the calcium carbide to form acetylene gas. The pressure produced after a given time is taken as an indication of moisture content.

A modification of the method is to mix calcium carbide with the material to be tested in a vessel so arranged that the evolved acetylene gas is discharged. The loss in weight is taken as an indication of the amount of moisture contained in the sample.

REPORT OF COMMITTEE D-9

ON

ELECTRICAL INSULATING MATERIALS[*]

Committee D-9 on Electrical Insulating Materials held three meetings during the past year. Two of these meetings were held in Atlantic City, N. J., on October 24 and 25, 1944, and on March 13, 14, and 15, 1945. A third meeting was held in New York, N. Y., on June 19 and 20, 1945.

At these meetings actions were taken which resulted in a proposed new tentative method, revisions in existing standards, and other changes in some of the standards for which Committee D-9 is responsible. Projects which are still under way are mentioned later in this report.

The Advisory Committee held a joint meeting with the Advisory Committee of Committee D-20 on Plastics in Philadelphia, Pa., in December, 1944.

RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS

Subsequent to the 1944 Annual Meeting, Committee D-9 presented to the Society, through Committee E-10 on Standards, the following recommendations:

Emergency Specifications for:

Communication and Signal Pin-Type Lime-Glass Insulators (ES - 41),

Revision of Tentative Specifications for:

Laminated Thermosetting Materials (D 709 - 43 T), recommended jointly by Committee D-9 and Committee D-20 on Plastics,

Flexible Varnished Tubing Used in Electrical Insulation (D 372 - 40 T),

Black Bias-Cut Varnished Cloth Tape Used for Electrical Insulation (D 373 - 39 T),

Revision of Tentative Methods of:

Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 - 44 T),

Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 - 43 T),

Tentative Revision of Standard Methods of:

Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 - 43), and

Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 43).

The emergency standard was accepted by Committee E-10 on August 28, 1944, the revision of Tentative Specifications D 709 was accepted[1] on December 11, 1944, and the remainder of the recommendations on December 22, 1944. The emergency specifications, the revised tentatives, and the tentative revisions appear in the 1944 Book of A.S.T.M. Standards, Part III.

On January 9, 1945, the Standards Committee accepted[1] the joint recommendation of Committee D-9 and Committee D-20 on Plastics that the Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for

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[*] Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-9 reported the following results of the letter ballot vote of a total of 60 ballots returned from a committee membership of 111: **D 709**, affirmative 28, negative 0, ballots marked "not voting" 32; **D 372** and **D 373**, affirmative 20, negative 0, ballots marked "not voting" 40; **D 150**, affirmative 40, negative 0, ballots marked "not voting" 20; **D 295**, affirmative 23, negative 0, ballots marked "not voting" 37; **D 350**, affirmative 21, negative 1, ballots marked "not voting" 38; **D 229**, affirmative 31, negative 0, ballots marked "not voting" 29; **D 618**, affirmative 34, negative 1, ballots marked "not voting" 25.

Testing (D 618 – 44 T) be revised. The revised tentative methods also appear in the 1944 Book of A.S.T.M. Standards, Part III.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE METHOD			
Test for Gas Content of Insulating Oils	21	0	52
II. REVISION OF TENTATIVES			
Testing Molded Materials Used for Electrical Insulation (D 48 – 43 T)	32	2	39
Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 44 T)	49	0	24
Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 44 T)	25	0	48
Spec. for Flexible Treated Cotton and Rayon Sleeving Used in Electrical Insulation (D 372 – 44 T)	26	0	47
Conditioning and Classifying for Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 44 T)	43	0	30
Spec. for Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 – 43 T)	21	1	51
Method of Flexural Test of Plastics (D 790 – 44 T)	42	0	31
III. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Test for Insulating Resistance of Electrical Insulating Materials (D 257 – 38)	41	0	32
Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 43)	25	0	48
IV. TENTATIVE REVISION OF STANDARD			
Testing Electrical Insulating Oils (D 117 – 43)	34	0	39

RECOMMENDATIONS AFFECTING STANDARDS

As the result of the year's work, the committee is submitting one new tentative method, revisions in seven tentative specifications and methods of test, tentative revision of a standard, revisions of two standards for immediate adoption, and a new statement on the Significance of Tests for Resistivity. The standards affected are listed in Table I. The recommendations being presented are included in Appendix I, each proposed revision being accompanied by a brief reason for the revision.

These recommendations have been submitted to letter ballot of the committee which consists of 111 voting members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Since the 1944 Annual Meeting of the Society, this committee has suffered the loss of C. F. Hanson, who died on April 27, 1945. Mr. Hanson has served as chairman of Subcommittee I on Insulating Varnishes for many years and his loss will be keenly felt.

Of particular note among the subcommittee activities are two conferences held during the past year with representatives of the Armed Services standardizing agencies. The first of these, held in New York, N. Y., on February 14, 1945, was concerned with methods of testing insulating varnish films for resistance to sea water and other alkalies and acids. The second held in Philadelphia, Pa., on April 24, 1945, was concerned with methods of testing the insulation resistance of solid dielectrics. Both conferences were called at the request of the Service Groups to consider closer cooperation and correlation of test procedures in the specifications used by the Service Groups and in A.S.T.M. Standards.

Some of the projects now in progress are briefly mentioned in the following summary of subcommittee activities:

Subcommittee I on Insulating Varnishes, Paints, and Lacquers (C. F. Hanson, chairman).—Four groups are actively working on projects in which considerable progress is being made. The Section on Thermosetting Varnishes has been running a series of interlaboratory tests to improve the methods of evaluating "set time" of these materials. Another section is revising and reediting the Standard Methods of Testing Varnishes Used for Electrical Insulation (D 115 - 41). A section which has been working with methods of evaluating the characteristics of deep-drying varnishes has been attempting for many years to find a satisfactory method of evaluation of these materials. A test procedure has been found which is to be tried out in a round-robin series of tests. Methods of testing the acid and alkali resistance of insulating films are to be reviewed and possible revisions are being considered.

Subcommittee II on Molded Insulating Materials (W. A. Evans, chairman).—To check the test methods and to provide specification requirement values, a round-robin test on various sizes and formulations of extruded flexible plastic tubing has been started.

Revisions are recommended in the Tentative Methods of Testing Molded Materials Used for Electrical Insulation (D 48 - 43 T) to bring them up to date.[2]

The requirements for a nontarnishing type of material are being obtained and assembled for inclusion in the Tentative Specifications for Phenolic Molding Compounds (D 700 - 43 T).

The specifications for melamine, urea, and various thermoplastics, developed by Committee D-20 on Plastics are being examined. If adequate for electrical insulation, electrical requirement values will be supplied, where necessary, so that they may be approved by Committee D-9.

Subcommittee III on Plates, Rods, and Tubes (G. H. Mains, chairman).—As the result of the continued cooperation of Subcommittee III with Subcommittees II and XIII of Committee D-9 and Subcommittee I of Committee D-20 on test methods for mechanical properties of sheets, rods, and tubes, the new Tentative Method of Flexural Test of Plastics (D 790 - 44 T) was developed, also a revision was made in the Tentative Method of Test for Tensile Properties of Plastics (D 638 - 44 T).

Tentative revisions of the Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 43) have also been issued to conform with these revised methods, and it is planned to recommend them for adoption as standard next year.

In cooperation with Subcommittee VI of Committee D-20, a new revision of the Tentative Specifications for Laminated Thermosetting Materials (D 709 - 44 T) has been prepared to include values on impact strength for all grades of sheet, and to add new property values for various grades of rods.

In line with the decision of the Advisory Committees of Committee D-9 and Committee D-20, Subcommittee III has arranged to turn over its investigational work on test methods for mechanical properties of electrical insulating materials having to do with plastics to Subcommittee I of Committee D-20 and that on thermal properties of the same materials to Subcommittee III of Committee D-20. On these properties for other insulating materials under its jurisdiction it will so far as possible use the test methods developed by Committee D-20.

Some of these pending items include a study of the relation of total pendulum energy in the Izod impact test to the actual value calculated for the higher impact materials, the study of bond strength of laminated materials, the heat distortion of laminated thermosetting materials, and flammability tests.

Work is continuing on the study of the effect of specimen size and of various types and periods of conditioning on insulation resistance of sheet materials. Preliminary data have been obtained on the effect of high and low temperatures on power factor and dielectric constant of sheet insulating materials, and more extensive data will be available shortly.

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[2] These revised specifications and methods were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

Subcommittee IV on Liquid Insulation (E. A. Snyder, chairman):

Sludge Test.—Correlating tests to determine the relation of test data obtained by the Tentative Methods of Test for Sludge Formation in Mineral Transformer Oil (D 670 - 42 T) with actual service life of transformer oils, as referred to in the 1944 report,[3] are under way and it is hoped that a preliminary report showing trends of the results of the investigation will be available for inclusion in next year's report. Some preliminary data have been obtained to date but they are still too meager to be of any value in this study.

Tests will probably have to extend over a period of at least five years in order to obtain sufficient data on which to base tentative conclusions.

Resistivity and Power Factor Test.—The proposed method for determination of resistivity and power factor of petroleum insulating oils as given in the Appendix is submitted for publication as a tentative revision of the Standard Methods of Testing Electrical Insulating Oils (D 117 - 43).

Gas Content of Insulating Oils.—The routine and referee procedures in the Methods of Test for Gas Content of Insulating Oils, as printed in Appendix III of the 1944 report,[3] are being recommended for publication as tentative this year.[4]

Dielectric Strength Test.—A new tentative revision of the dielectric strength test in Standard Method D 117, given in the Appendix to this report, was prepared during the year and is recommended for publication to replace the present tentative revision.[5]

Tests for Askarels.—The Methods of Test for Askarels, which were published as information in Appendix IV of the 1943 report, have been revised and the revised methods are appended to this report.[6] As methods for determination of dielectric strength and power factor of askarels are still under study, Subcommittee IV is not ready to recommend the methods for publication as tentative, but the methods as developed and revised to date are being again published as information to elicit comments and criticism.

Questionnaire on Tests of Transformer Oils in Service.—Subcommittee IV conducted a study during the year on the importance of the various test methods for determining quality of insulating oils. In connection with this study, L. B. Schofield prepared and circulated a questionnaire to approximately 80 utilities in the United States and Canada to determine each utility's opinion on the following questions:

1. The relative order, in their opinion, of the importance of tests which they consider significant in testing transformer oil to judge its suitability for continued use,

2. Tests which they always make to appraise serviceability of oil and their allowable limits for each test,

3. Whether periodic tests are made at fixed time intervals and what the time intervals are,

4. What supplementary tests are made in addition to those noted under item *2*,

5. What tests they have investigated in the past and abandoned as being of no real value, and

6. Whether sludging of oil is a serious problem and if so, what steps are taken to reduce sludging or to eliminate the cause of sludging.

Very cooperative and helpful answers were received from practically all these utilities and the results of this questionnaire have been tabulated and analyzed and presented by Subcommittee IV to Committee D-9 for publication as a paper for presentation to the Society. It is the belief of Subcommittee IV that the information gathered and so tabulated will be of extreme interest to all users of electrical apparatus, especially transformers. It appears as Appendix III to this report.

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 422 (1944).

[4] These methods were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[5] 1944 Book of A.S.T.M. Standards, Part III.

[6] See p. 292.

Water in Insulating Oils.—Work is still continuing in the development of a method of test to determine accurately and quantitatively the small traces of moisture present in insulating oils. A new series of round-robin tests with modified test methods has been initiated and the question will receive further study during the coming year.

Reorganization of Test Methods.—Subcommittee IV is actively studying a more desirable method of organizing the test methods under its jurisdiction. At its inception, Subcommittee IV was mainly concerned with the development of test methods to determine the characteristics of transformer oils. During the years the scope of its work increased very much and it now embraces the study of methods of test for transformer oils, switch oils, cable oils, and capacitor oils. Some of these oils require certain tests while others may not require the same tests. Also, in some cases test methods for certain characteristics which are applicable to transformer oils may require considerable modification to make them applicable to, for example, cable oils. The subcommittee is also engaged in developing test methods for liquid insulation other than that of petroleum origin. The program of Subcommittee IV is, therefore, directed toward the establishment of individual test methods for publication as separate A.S.T.M. Standards, and Methods D 117 will then become a collection of references to methods which will cover the definition of the test, the significance of the test, and references to the proper A.S.T M. methods which describe the test procedures. It is felt that a plan of organization of this type will be sufficiently elastic to allow for any future expansion and for easier revision of the methods when required.

Subcommittee V on Ceramic Products (L. J. Cavanaugh, chairman).—As mentioned earlier in this report, Emergency Specifications for Communication and Signal Pin-Type Lime-Glass Insulators (ES - 41)[5] have been prepared and issued. The publication of these specifications as tentative is now under consideration.

Progress has been made in the study relating to factors involved in the determination of loss factor of steatite after exposure to water.

Subcommittee VI on Solid Filling and Treating Compounds (R. H. Titley, chairman).—Work is under way looking toward the preparation of specifications for filling and treating compounds.

Subcommittee VII on Insulating Fabrics (R. W. Chadbourn, chairman).—During the past year, the subcommittee prepared a number of revisions in the test methods and specifications for varnished cambric tape. One of the most important was the replacement of the existing method for making dielectric strength tests after elongation by a new method in which the tape is stretched at a definite rate to an elongation of 6 per cent and held at that elongation while the tape is tested to breakdown. This is felt to approximate much more closely actual conditions of use. It is recognized, however, that greater elongations are commonly experienced in practice, so users of tape are requested to accumulate data on breakdowns at 12 per cent elongation, so that further modification of the method may be made as may seem necessary.

Conditioning at 50 per cent relative humidity, instead of 65 per cent, has been adopted for varnished cambric and also for treated sleeving. This brings the pretest treatment of these materials into line with that used for other insulations.

An alternative method of test for power factor of varnished cambric, involving conditioning at 50 per cent humidity, has been adopted. The subcommittee recognizes that this material is sometimes used in locations where the humidity is high, and provision for a dielectric test at high humidities is contemplated.

Objection has been raised to the step-by-step dielectric test, as applied to varnished cambric, because of the excessive number of steps, and the subcommittee has begun to investigate the possibility of a substitute for this test, in which the voltage would be raised uniformly to breakdown, as in the short-time test, but at such a reduced rate that the results would be comparable with those now obtained on the step-by-step test.

The statements on significance of tests that were prepared some time ago have been revised in accordance with the model adopted by Subcommittee XI, and are now being submitted for final approval by the committee.

Several changes are contemplated in the six tests already adopted for treated glass fabrics, as now detailed in the Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 – 44 T).[5] It has been found, for instance, that the dielectric strength tests now prescribed for varnished cambric do not apply, in all details, to glass fabrics because of the differences in breakdowns of the two materials. Again, because of the higher temperatures to which glass fabrics are subjected, changes in the temperatures prescribed for power factor tests seem desirable. In addition to the changes proposed in existing methods, several additional tests have been suggested for study.

In response to a request from the industry, a section has been formed to develop test standards and specifications for adhesive tape for electrical applications.

Subcommittee VIII on Insulating Paper (C. T. Hatcher, chairman).—The members of this subcommittee are working with the members of Committee D-6 on Paper and Paper Products in the development of test procedures for insulating papers that are satisfactory to both groups. A group working on developing a pH method for acidity determinations of paper is about ready to submit a proposed method for publication as tentative. A section on mechanical strength is considering the submission of a tensile strength method which has been developed in conjunction with Committee D-6. Revisions in the Tentative Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 44 T), satisfactory to both groups, are being recommended at this time.

Subcommittee IX on Mica Products (E. O. Hausmann, chairman).—Revisions in the Tentative Specifications for Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 – 43 T) are being recommended this year.[2] At the request of the U. S. Bureau of Supplies it was decided to reconsider the standardization of color photographs for grading of natural mica. This project had been tabled at one time during the year.

Subcommittee X on Conditioning (R. Burns, chairman).—In addition to coordinating the conditioning procedures of the various subcommittees of Committee D-9 and Committee D-20, and integrating the activities with other standing committees throughout the Society, the principal project of this subcommittee has been the standardization of procedures applying particularly to insulating materials and plastics. These are embodied in the revised Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for

Testing (D 618 - 44 T) which are appended hereto[2] and consist of (*a*) standard laboratory atmosphere — 50 per cent relative humidity at 25 C., and (*b*) drying at 50 C. for 48 hr. A list of standard test temperatures ranging from -70 C. to +105 C. is also included. The subcommittee, in a desire to eliminate confusion when the term "room temperature" is used, has defined standard room temperature as "An atmosphere of unspecified relative humidity at a temperature in the range 20 to 30 C." It was further decided that Committees D-9 and D-20 will use the Centigrade scale, with Fahrenheit in parenthesis, as the standard manner of expressing temperature.

Subcommittee XI on Significance of Test (H. L. Curtis, chairman).—Attention has been given to the form and content of the Statements of Significance of Tests. General principles were decided upon and an editorial committee consisting of Messrs. Gordon Thompson, R. W. Chadbourn and P. H. Dike, was appointed to insure that these principles are embodied in future statements of significance.

The significance of the test for resistivity of insulating materials was revised[7] and has been submitted to Committee D-9 for letter ballot.

At the suggestion of Subcommittee XI, Subcommittee IV has prepared a new type of statement for transformer oils. In this statement the various properties of oil are listed and their significance given with a reference to a standard method for making the test.

Subcommittee XII on Electrical Tests (Gordon Thompson, chairman).—This subcommittee has five active sections. The section on methods of test for resistivity and insulation resistance has been studying long-time charging-current curves; the preparation of a statement of significance of test has raised considerable discussion. The section on measurement of power factor of liquids is working with a group in Subcommittee IV. The power factor of solid insulating materials at frequencies all the way up to hundreds of megacycles per second is the concern of a third section and with the removal of restrictions in the field of "ultra-high-frequencies" this section will have plenty of work to do; a program of testing various types of electrode materials and methods of application is in preparation. The section on arc resistance tests is reviewing the present methods thoroughly and carrying on round-robin tests based on new techniques and procedures.

Subcommittee XIII on Mechanical Tests (F. G. Tatnall, chairman).—This subcommittee is actively engaged in correlating the work of Committees D-9 and D-20 on flexure testing. It is also studying the various methods for compression testing used by Committee D-9 and will attempt to correlate these methods with those used by other committees of the Society. A section for investigating the various methods used in tension testing has also been formed.

This report has been submitted to letter ballot of the committee which consists of 111 voting members; 60 members returned their ballot, of whom 55 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

MYRON PARK DAVIS,
Chairman.
W. A. EVANS,
Vice-Chairman.

W. A. ZINZOW,
Secretary.

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[7] "Significance of Tests of Electrical Insulating Materials," compilation of "A.S.T.M. Standards on Electrical Insulating Materials," October, 1945, p. 27.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 9, recommendations affecting tentatives and a tentative revision of a standard referred to in the report were submitted by Committee D-9 and accepted by the Administrative Committee on Standards on June 27, 1945. The new and revised tentatives and the tentative revision appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

Subsequent to the Annual Meeting, Committee D-9 recommended to the Administrative Committee on Standards that the Specifications for Molds for Test Specimens of Molding Materials Used for Electrical Insulation (D 647 – 42 T) be revised. This recommendation was accepted by the Standards Committee on December 8, 1945 and the revised specifications also appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

On December 12, 1945, the Standards Committee accepted the joint recommendation of Committee D-9 and Committee D-20 on Plastics that the Tentative Specifications for Phenolic Molding Compounds (D 700 – 43 T) be revised. The revised tentative appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS ON ELECTRICAL INSULATING MATERIALS

In this Appendix are given recommendations affecting certain standards and tentatives covering electrical insulating materials which are referred to earlier in this report.[1] The standards and tentatives appear in their present form in the 1944 Book of A.S.T.M. Standards, Part III.

New Tentative Method

Tentative Methods of Test for Gas Content of Insulating Oils:[2]

These methods are intended for determining gas content of insulating oils such as are used in capacitors and paper-insulated lead-covered cables of the oil-filled type. Two methods are covered: a routine method, and a referee method for use when a test of high accuracy is desired. These methods of test were published as information in connection with the 1944 Report of Committee D-9.[3] It is recommended that these methods be accepted for publication as tentative.

Revision of Tentatives

Tentative Methods of Testing Molded Materials Used for Electrical Insulation (D 48 - 43 T):

This revision consists of a complete new form of this standard. The revision has been considered for some time and consists largely of a rearrangement of the present methods together with the addition of references to other test procedures which have heretofore not been included. Only minor changes in the test procedures are involved. The methods as revised[4] represent a complete directory of A.S.T.M. methods of test applicable to the types of insulating materials that are covered by the standard.

Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 - 44 T):

Revisions of these methods are largely clarifications of changes concerning capacitances to be used in the test procedures making it permissible to use a wider latitude of capacitances most suitable to the equipment available. Another part of these revisions concerns descriptions of test cells suitable for liquid insulating materials. The test methods are not changed in any essential details.

Section 11 (*b*).—After the second sentence, insert the following two sentences:

> The capacitance of the specimen shall be, preferably, not less than 70 $\mu\mu$f. However, it is not intended that this minimum value be rigidly adhered to, providing the precision of the measurement meets the intended accuracy of the test method.

Section 11 (*c*).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

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[1] For an explanation of these revisions, see p. 276.

[2] These methods were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 450 (1944).

[4] These revised specifications and methods were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

(*c*) For testing rolled or laminated tubes or ceramic tubes, the test specimen shall have the diameter and wall thickness of the material it represents, and shall be of sufficient length to provide a capacitance [of] *preferably* not less than 70 μμf. *However, it is not intended that this minimum value be rigidly adhered to, providing the precision of the measurement meets the intended accuracy of the test method.* The thickness shall be uniform to plus or minus 5 per cent, and the surfaces shall be smooth and free from irregularities.

Section 11 (*d*).—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

The liquid shall be tested in a suitable test cell in which the ratio of surface to thickness of liquid layer is sufficient to [give] *provide* a capacitance [of] *preferably* not less than 70 μμf. *However, it is not intended that this minimum value be rigidly adhered to, providing the precision of the measurement meets the intended accuracy of the test method.* [One] *Two* [form] *forms* of test [cell] *cells* that [has] *have* been found satisfactory [except for extra high quality oils] *for testing oil with power factors ranging from 0.0001 to 0.25* [is] *are* shown in Appendix III [to the Standard Methods of Testing Solid Filling and Treating Compounds Used for Electrical Insulation (A.S.T.M. Designation: D 176) of the American Society for Testing Materials]. *Another form of test cell that has been found satisfactory, except for extra-high-quality oils, is also shown in Appendix III.*

Section 13 (*b*).—Omit the first sentence.

Section 13 (*d*).—Omit the fifth sentence. Change the seventh sentence to read as follows by the addition of the italicized words: "Also, the construction of the cell must be such that in the cleaning operation all traces of a former specimen *or cleaning solvent* can be completely removed."

Tentative Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 44 T):

These revisions are largely changes recommended by a section which has been correlating the methods of test used by Committee D-6 on Paper and Paper Products and Committee D-9.

Sections 8 to 12.—Substitute for these sections the following new sections, 8 and 9, renumbering the subsequent sections accordingly:

8. *Weight.*—The determination of weight shall be made in accordance with the Tentative Method of Test for Basis Weight of Paper and Paper Products (A.S.T.M. Designation: D 646), except for sampling and conditioning of the sample which shall be carried out in accordance with Sections 2 and 3 of Methods D 202. The results shall be reported as weight in grams per square meter.

9. *Apparent Density.*—The apparent density shall be calculated from the thickness (Sections 5 to 7), area, and weight (Section 8) results obtained on conditioned specimens (Section 3), and reported as grams per cubic centimeter.

NOTE.—Apparent density may be calculated as follows:

$$D = \frac{\text{grams per square meter}}{\text{thickness in inches}} \times 0.0000394$$

$$D = \frac{\text{weight in grams}}{\text{volume in cubic inches}} \times 0.061$$

$$D = \frac{\begin{array}{c}\text{weight of 25 by 40 in.} - 500\\ \text{sheet ream in pounds}\end{array}}{\text{thickness in inches}} \times 0.0000554$$

$$D = \frac{\begin{array}{c}\text{weight of a 7-13/16 in.}\\ \text{square sample in grams}\end{array}}{\text{thickness in mils}}$$

where:

D = apparent density in grams per cubic centimeter.

Section 57.—At the end of this section on apparatus for impregnation add a note referring to Paragraph (*c*) to read as follows:

NOTE.—For comparative purposes liquids other than these may be used.

Sections 59 and 60.—Revise the procedure and section on report of the test for impregnation to read as follows:

59. *Procedure.*—(*a*) The test specimens shall be measured for thickness in accordance with Methods A or C of the Standard Methods of Test for Thickness of Solid Electrical Insulation (A.S.T.M. Designation: D 374).

(*b*) The test specimens shall be numbered consecutively on the same side of the paper.

The odd-numbered specimens shall be tested with their numbered sides up, that is, not in contact with the impregnating liquid. The even-numbered specimens shall be tested with their numbered sides down, that is, in contact with the impregnating liquid.

(*c*) The liquid container shall be placed in a horizontal position and the thermometer shall be so fixed that the bottom of its bulb is approximately ¼ in. above the container bottom. The container shall be filled with the impregnating liquid to within ¼ in. of the upper edge of the container orifice. The liquid shall be maintained at this level by adding small amounts of liquid to replace that absorbed by the test specimens during the testing period. The temperature of the liquid shall be maintained at 77 ± 2 F. during testing by means of the electrical heater or by the circulation of water through the jacket.

(*d*) The specimen shall be placed over the container orifice and clamped in place with the ring clamp. After setting the stop watch at zero, the container handle shall be depressed quickly until the front end of the container touches the base plate. The surface of the paper shall be observed closely and at the instant of complete penetration of the liquid throughout the entire paper area under test the watch shall be stopped by immediately raising the front end of the liquid container.

(*e*) The elapsed time shall be recorded as that of impregnation.

60. *Report.*—The report shall include the following:

(*a*) The average, maximum, and minimum times for total impregnation, in seconds,

(*b*) The average, maximum, and minimum thicknesses before impregnation, in inches, and

(*c*) Thickness of the specimen showing the maximum impregnation time and also the thickness of the specimen showing the minimum time.

Tentative Methods of Testing Varnished Cloths and Vanished Cloth Tapes Used in Electrical Insulation (D 295 – 44 T):

These revisions involve two changes: the first of which will include the humidity value being standardized for all insulating materials, and the second of which provides an alternative method of conditioning for power factor tests where vacuum treatment cannot be used or where it is desired to test the material at a power factor more closely approximating conditions of use.

Section 4.—Substitute for this section on conditioning the following:

4. (*a*) The test specimens shall be conditioned for 48 hr. in air maintained at a temperature between 20 to 30 C. and at a relative humidity of 50 ± 2 per cent.

(*b*) If a conditioning cabinet or chamber is used, test specimens shall be subjected to test immediately upon withdrawal from the cabinet or chamber, unless otherwise specified.

Section 40.—Change this section on conditioning of test specimens for power factor tests to read as follows:

40. The test specimens shall be conditioned by one of two methods:

(*a*) When the greatest duplicability of results is desired, the test specimens in one thickness, shall be heated to 105 ± 3 C. for 1 hr. without vacuum, and then for 2 hr. at 105 ± 3 C. in a vacuum having an absolute pressure not exceeding 1 mm. of mercury.

(*b*) When the vacuum treatment is not feasible, or when an approximation to conditions of use is desired, the test specimens shall be conditioned in accordance with Section 4.

(*c*) In the case of dispute, the vacuum treatment shall be considered the referee method.

Tentative Specifications for Flexible Treated Cotton and Rayon Sleeving Used in Electrical Insulation (D 372 – 44 T):

This revision is largely editorial in nature since the present wording has been found to permit of some misinterpretation.

Section 5.—Change to read as follows by the addition of the italicized words and the omission of those in brackets:

5. The number of hours of baking in the aging test [at] *during* which [first] *no* cracking of the [treated sleeving] *tubing* occurs when bent through 180 deg. over the rod specified in Section 14 of the Standard Methods of Testing Flexible [Treated Sleeving] *Varnished Tubing* Used for Electrical Insulation (A.S.T.M. Designation: D 350) shall be not less than the following:

Grades A-1, A-2, and C	96 hr.
Grades B-1 and B-2	72 hr.

Tentative Methods for Conditioning and Classifying for Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 44 T):

This revision concerns a rearrangement in form of these methods. It is the result of considerable discussion which has been going on for a period of time. It is designed to provide a standardized conditioning treatment suitable for conditioning materials of two types, one of which is a normal room temperature conditioning while the other is a conditioning treatment applied at an elevated temperature. These revised methods, appended hereto,[4] are being submitted jointly with Committee D-20 on Plastics.

Tentative Specifications for Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 - 43 T):

This revision consists of clarifying and broadening changes in these specifications. Formerly the specifications referred to American War Standards which reference is now deleted so as to make the specifications complete in themselves. None of the changes involved affect the methods of test required in any essential detail. The revised specifications are appended hereto.[4]

Tentative Method of Flexural Test of Plastics (D 790 - 44 T):

This revision involves minor changes, largely editorial in nature, which clarify this method. The following revision is accordingly recommended jointly with Committee D-20:

Section 8.—In Paragraph (*a*) add after "simple beam" the words "of rectangular cross-section."

Change the heading and the first sentence of Paragraph (*c*) to read as follows by the addition of the italicized words:

Flexural Offset Yield Strength.—The *flexural* offset yield strength is the stress at which the stress-strain diagram for the material departs from the initial direction of the curve by a specified increment of strain.

Table I.—To the recommended test specimens in this table insert the following three additional sizes in proper numerical position:

Nominal Thickness of Sheet, in.	3/32	3/16	3/8
Span, min., in.	1½	3	6
Flatwise:			
Depth of Specimen, in.	3/32	3/16	3/8
Width of Specimen, in.			
Min.	½	½	½
Max.	½	½	½
Edgewise:			
Depth of Specimen, in.	3/32	3/16	3/8
Width of Specimen (Nominal Thickness, in.)	3/32	3/16	3/8

Section 3 (*a*).—Add a new note 4 to read as follows:

NOTE 4.—For comparing values the thickness of specimens being compared should be approximately equal.

Section 4.—Insert the following new Paragraph (*c*), relettering the present Paragraph (*c*) as (*d*):

(*c*) For sheet materials the specimens shall be tested as follows:

(*1*) Five specimens cut lengthwise of the sheet, tested flatwise.

(*2*) Five specimens cut lengthwise of the sheet, tested edgewise.

(*3*) Five specimens cut crosswise of the sheet, tested flatwise.

(*4*) Five specimens cut crosswise of the sheet, tested edgewise.

Section 6 (*b*).—Change to read as follows by the addition of the italicized word: "The rate of crosshead motion for testing flexural specimens shall be *calculated* in accordance with the following formula:"

In the sentence following the formula insert the italicized words to read: "The rate of crosshead motion shall *be as near as possible but shall* not exceed the value calculated from the above formula."

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Methods of Test for Insulation Resistance of Electrical Insulating Materials (D 257 – 38):

These revisions are concerned with changes necessary to make these methods more suitable for measurements on liquid insulating materials. They deal entirely with the cells to be used for such measurements.

Section 7.—Change Note 2 from its present form: namely,

NOTE 2.—Because of the catalytic action of some metals on oils, the electrodes shall be plated with nickel, gold, or platinum.

to read as follows:

NOTE 2.—The electrode surfaces shall be made of a material capable of resisting attack by mild acids found in certain insulating oils such as petroleum oil, particularly after prolonged exposure to elevated temperatures. Metals which have been found satisfactory from this standpoint are gold, nickel, monel, and platinum. In general, plated surfaces have been found less satisfactory than solid metal electrodes.

Insert the following new Note 3, renumbering the present Note 3 as Note 4:

NOTE 3.—Any of the cells mentioned in A.S.T.M. Methods D 150, Section 11 (*d*), are satisfactory for use in resistivity measurements.

Methods of Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 43):

This revision is concerned with bringing the humidity conditioning requirement for treated sleeving into line with that specified for the conditioning of other insulating materials.

Section 3.—Delete Paragraph (*a*) and change Paragraph (*b*) to read as follows:

3. (*a*) The test specimens shall be conditioned for 48 hr. in air maintained at a temperature between 20 and 30 C. and at a relative humidity of 50 ± 2 per cent. If a conditioning cabinet is used, specimens used for dielectric strength tests shall be subjected to test immediately upon withdrawal from the cabinet.

TENTATIVE REVISION OF STANDARD

Standard Methods of Testing Electrical Insulating Oils (D 117 – 43):

The first of these changes are editorial changes in the names of two sections and do not involve any change in the methods.

The second change involves a complete substitution for the tentative revision accepted in June, 1940, and subsequently modified in June, 1943, and June, 1944.[5] This new form of the description of the dielectric strength test procedure as applied to insulating oils is the result of a series of revisions made since 1940. It is being presented in this form at this time as a tentative revision of Sections 22 to 28, inclusive.

The third revision concerns new descriptive matter about test cells and their care which are to be used for power factor, dielectric constant, and resistance measurements.

Section 14.—Change the title of this section from "Acid and Base Numbers" to read "Strong Base and Strong Acid Neutralization Number."

Section 17.—Change the title of this section from "Mineral Acids (Chlorides and Sulfates)" to read "Inorganic Salts (Chlorides and Sulfates)."

Sections 22 to 24.—Change from their present form to read as follows:

DIELECTRIC STRENGTH

22. *Apparatus:* (*a*) *Transformer.*—The desired test voltage may be most readily obtained by a set-up transformer energized from a variable low-voltage source. The transformer and its controlling equipment shall be of such size and design that, with the test specimen in circuit, the crest factor (ratio of maximum to mean effective) of the test voltage shall not differ by more than plus or minus 5 per cent from that of a sinusoidal wave over the upper half of the range of test voltage. The crest factor may be checked by means of an oscillograph, or a sphere-gap or peak-reading voltmeter in conjunction with an rms. voltmeter. Where the wave-form cannot be determined conven-

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[5] 1944 Book of A.S.T.M. Standards, Part III.

iently, a transformer having a rating of not less than 2 kva. shall be used. Tests shall be made at commercial power frequencies.

NOTE.—When a transformer is used at voltages lower than its full rating, the current drawn from the high voltage winding should not exceed the full-load full-voltage current rating.

(*b*) *Circuit Breaker.*—The test transformer circuit shall be protected by an automatic circuit-breaking device designed to open substantially instantaneously on the current produced by breakdown of the test specimen. A prolonged flow of current at the time of breakdown causes carbonization of the liquid and pitting and heating of the electrodes, and thereby increases the work of electrode and test cup maintenance, and time of testing.

(*c*) *Voltage Control.*—The rate of voltage rise shall not, for short-time tests, vary more than plus or minus 25 per cent from the specified rate. Control of voltage may be secured in one of several ways:

(*1*) variable-ratio auto-transformer,
(*2*) resistance-potential divider,
(*3*) generator-field regulation,
(*4*) induction regulator, or
(*5*) adjustable resistance in the primary circuit.

Preference should be given to equipment having an approximately straight-line voltage-time curve over the desired operating range. Motor drive, with variable speed control, should be preferred to manual drive because of the difficulty of maintaining a reasonably uniform rate of voltage rise with the latter.

(*d*) *Voltmeter.*—The voltage shall be measured by an approved method which gives root-mean-square values, preferably by means of:

(*1*) A voltmeter connected to the secondary of a separate potential transformer,
(*2*) An electro-static voltmeter in the high-voltage circuit, or
(*3*) A voltmeter connected to a well-designed tertiary coil in the test transformer.

A voltmeter connected to the low-voltage side of the testing transformer may be used only if the ratio of transformation does not change appreciably with load.

(*e*) *Rate of Rise of Voltage.*—The rate of voltage rise may be calculated from measurements of time required to raise the voltage between two prescribed values. When motor-driven regulating equipment is used, the speed-control rheostat may be calibrated in terms of voltage rise for any particular test transformer.

23. *Electrodes.*—The electrodes shall be polished metal disks 1 in. in diameter with square edges, mounted with axes horizontal and coincident.

24. *Test Cup.*—A special test cup with the electrodes rigidly mounted with their axes in a horizontal line shall be used. The test cup should be of such design that no part of it is less than ½ in. from any part of the test faces of the electrodes, when the latter are in the testing position. The total leakage and charging current of the test cup, when filled with a good grade of insulating oil, shall be less than 200 microamperes at 20 kv., 60 cycles. The test cup shall be made of a material of high dielectric strength, must be insoluble in, and unattacked by, any of the cleaning or test liquids, and nonabsorbent to moisture, and the cleaning and test liquids. Wood is not a suitable material for the test cup. The top of the cup should be about 1¼ in. (33 mm.) above the top of the electrodes.

25. *Adjustment and Care of Electrodes and Test Cup.*—(*a*) The electrodes and the test cup shall be wiped clean with dry, calendered tissue paper or with a clean, dry chamois skin. The spacing of the electrodes of the test cup shall be checked with a standard round gage having a diameter of 0.100 in. or flat steel "go" and "no-go" gages having thicknesses of 0.0995 and 0.1005 in., respectively, and the electrodes locked in position. It is important to avoid touching the electrodes or the cleaned gage with the fingers or with portions of the tissue paper or chamois skin which have been in contact with the hands. The electrodes and cup shall then be rinsed with dry lead-free gasoline, Stoddard solvent, or dry, water-white kerosine until they are entirely clean. Care shall be taken not to touch the electrodes or the inside of the cup after cleaning, so as to avoid any possible contamination. After thoroughly cleaning the test cup, it shall be filled with a sample of the cleaning fluid and voltage applied with uniform increase at the rate of approximately 3 kv. per sec. (rms. value) until breakdown occurs. If the breakdown is not less than the established value of the oil being tested, the cup shall be considered in suitable condition for testing. If a lower value is obtained, the cup shall again be thoroughly cleaned and the test repeated. A cleaning fluid whose breakdown is not less than the established value of the oil being tested must be used.

(*b*) At the beginning of each day's testing, the electrodes shall be examined for pitting and carbon accumulation, and the spacing checked. The cup shall be thoroughly cleaned and tested as described in Paragraph (*a*). It shall then be flushed with a portion of the sample to be tested before it is filled for the test.

(*c*) If the test of a sample is below the breakdown value being used by the operator as a minimum satisfactory value, the cup shall be cleaned and prepared as described in Paragraph (*a*) before testing the next sample.

NOTE.—Evaporation of the cleaning fluid

from the electrodes may chill them sufficiently to cause moisture to condense on their surfaces. For this reason, after the final rinsing with cleaning fluid, the cup must immediately be flushed with the oil to be tested, following which the cup should be filled for the test.

26. *Procedure:* (*a*) *Preparation of Sample.* The dielectric strength of liquid dielectrics may be markedly altered by the migration of impurities through the liquid. In order that representative test specimens may be obtained, the container shall be gently tilted or inverted and the oil swirled several times, before each filling of the test cup, in such a way that any impurities present will be thoroughly mixed with the dielectric. Too rapid agitation is undesirable, as it introduces an excessive amount of air into the mixture. Immediately after mixing, the test cup shall be filled with oil to a height of not less than 20 mm. (0.787 in.) above the top of the electrodes. In order that entrapped air may escape, the container shall be gently rocked a few times and the oil allowed to stand in the cup for 3 min. before voltage is applied.

(*b*) *Temperature of Test.*—The temperature of the sample when tested shall be the same as that of the room, but the room temperature shall in no case be less than 20 C. (68 F.). Testing at oil temperatures lower than room temperatures is likely to give variable results which may be misleading.

(*c*) *Application of Voltage.*—Voltage shall be applied and increased at a uniform rate of 3 kv. per sec. from zero until breakdown occurs as indicated by a continuous discharge across the gap. (Occasional momentary discharges which do not result in a permanent arc may occur; these should be disregarded.)

27. *Number of Tests:* (*a*) Except as specified in Paragraph (*b*), one breakdown test shall be made on each of five fillings of the test cup. If the average deviation from the mean exceeds 10 per cent or if any individual test deviates more than 25 per cent from the average, additional tests shall be made. The dielectric strength shall be determined by averaging the first five tests that conform to the permissible variations.

(*b*) When oil is tested in considerable quantity, so that the time required for testing in accordance with Paragraph (*a*) is excessive, and when it is merely desired to determine whether the breakdown safely exceeds the limit specified, or in those cases where the amount of oil available for test may be very limited, one breakdown test shall be made on each of two fillings of the test cup. If neither breakdown is below this value, the oil may be considered satisfactory and no further tests shall be required. If either of the two breakdowns is less than the specified value a breakdown shall be made on each of three additional fillings and test results analyzed in accordance with Paragraph (*a*).

28. *Report.*—The report shall include the following:

(*1*) Procedure used, whether Paragraph (*a*) or (*b*), Section 27.

(*2*) The volts (rms. value) at each breakdown and the average of the five breakdowns. All results shall be reported to the nearest kilovolt.

(*3*) The approximate temperature of the oil at the time of the test.

Tentative revision, submitted, June, 1940; Modified, June, 1943; June, 1944.

Power Factor and Resistivity.—Add the following new sections covering test procedures for power factor and resistivity, including an Appendix describing the test cells:

POWER FACTOR AND RESISTIVITY

29. *General.*—Power factor and resistivity shall be determined in accordance with the general procedures outlined in the Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (A.S.T.M. Designation: D 150),[5] and Standard Methods of Test for Insulation Resistance of Electrical Insulating Materials (A.S.T.M. Designation: D 257).[5]

30. *Apparatus.*—The cell to be used for testing the oil shall be suitable for measuring power factors ranging between values of 0.0001 and 0.25. One form of test cell has been found satisfactory and is described in the Appendix. Cells of slightly different construction from the one described have been used with satisfactory results.

APPENDIX

REQUIREMENTS FOR CELLS USED FOR MEASURING LOW POWER FACTOR LIQUIDS

A1. *Design of Cell.*—A cell for the purpose of measuring power factor and resistivity of electrical insulating oils should meet the following general requirements:

(*a*) The design of the cell shall be such as to facilitate easy and thorough cleaning. The design, also, shall conveniently permit the use of the cell in a suitable temperature bath and means shall be provided for measuring the temperature of both electrodes.

(*b*) The materials used in constructing the cell shall be capable of satisfactorily withstanding temperatures up to 130 C. and the alignment of the electrodes shall not be influenced by this temperature.

(*c*) The electrodes or their surfaces shall be made of a metal capable of resisting attack by mild acids found in certain insulating liquids such as petroleum oil, particularly after prolonged exposure at elevated temperatures. Metals which have been found satisfactory from this standpoint are gold, nickel, monel, and platinum. In general, plated surfaces have been found less satisfactory than solid metal electrodes for measuring low power factor liquids. Plated surfaces that may be satisfactory for testing liquids with low acidity and for short periods of time are gold, platinum, nickel, chromium over nickel, or rhodium.

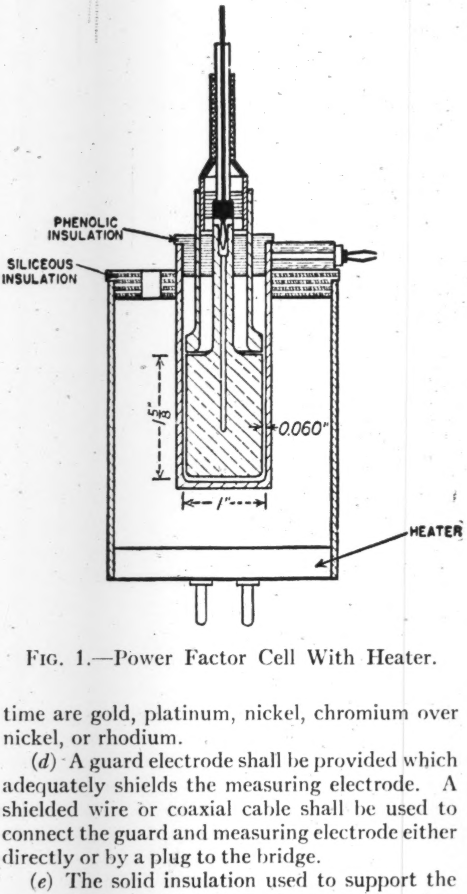

FIG. 1.—Power Factor Cell With Heater.

(*d*) A guard electrode shall be provided which adequately shields the measuring electrode. A shielded wire or coaxial cable shall be used to connect the guard and measuring electrode either directly or by a plug to the bridge.

(*e*) The solid insulation used to support the guard electrode relative to the measuring electrode shall not extend into the portion of the sample being tested.

(*f*) The insulating materials used in constructing the cell shall not absorb or be adversely affected by the test liquids, or cleaning solvents. Their power factor is preferably low, particularly that between the guard and measuring electrodes, otherwise difficulty may be experienced in balancing the guard circuits at elevated temperatures. Insulating materials that have proven satisfactory are pyrex glass, quartz, steatite, and the better phenolic resin compounds. Thermoplastic materials such as hard rubber and polystyrene, although having good electrical properties, are not suitable as they soften below 130 C. Insulating materials of the molded mica-dust type have been found to absorb solvents and therefore may not be satisfactory in the measurements of low power factor liquids. However, they are excellent materials for supporting the cell in the temperature bath.

(*g*) In designing the cell the distance across the surface of the oil and across the solid insulating material, between the guard and the measuring electrode, shall be great enough adequately to withstand the testing potential used. Leakage across these paths has been found to produce an unsteady bridge balance on some bridges.

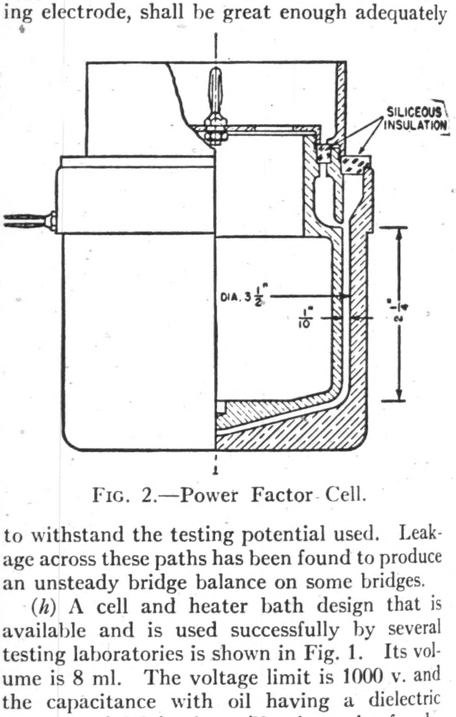

FIG. 2.—Power Factor Cell.

(*h*) A cell and heater bath design that is available and is used successfully by several testing laboratories is shown in Fig. 1. Its volume is 8 ml. The voltage limit is 1000 v. and the capacitance with oil having a dielectric constant of 2.2 is about 70 micro-microfarads.

(*i*) For routine work, cells on the same design principles, with particular attention to quickness of assembly and suitable for higher voltages may be desirable. Several laboratories use cell designs similar to Fig. 2 which are commercially available. This design requires about 90 ml. of oil and is suitable for use up to 3 kv. the capacitance with oil being about 180 microfarads.

A2. *Cleaning Procedure.*—The following is a suggested method for cleaning the cell:

(*a*) Fill the test cell with technical grade carbon tetrachloride, insert the inner electrode and bring to a boil on a hot plate. Empty, and repeat this procedure until the carbon tetrachloride poured off is clean.

(*b*) Wash the inner and outer electrodes with lava soap and water to remove films left by the carbon tetrachloride, taking precautions not to lay the inner electrode on any surface. The use of the lava soap will keep the cell surfaces polished. Rinse all surfaces with distilled water. Place the cell in an oven and maintain at 115 C. for at least 1 hr. prior to taking measurements.

A3. *Filling the Cell.*—(*a*) Remove the cell from the oven and rinse the electrodes with some of the sample oil to be tested which has been heated to approximately the test cell temperature. Fill the cell with the sample oil which has been heated to approximately the test cell temperature. Permit the assembly to cool to approximately the temperature at which the measurements are to be taken and place in a temperature-controlled device. Remove bolts and handles and connect the cell to the measuring bridge using the guard screen. Measure when the temperature is within plus minus 0.5 C. of the required value.

(*b*) Remove the inner electrode, pour off this sample and refill with a second, taking the same precautions as were observed in the first filling and make another measurement. If these two values disagree by more than 0.0001 + 10 per cent of the measured power factor, refill and make a third measurement.

(*c*) If the third value does not agree with either the first or second measured values to within 0.0001 + 10 per cent of the measured power factor, reclean the cell and repeat the procedure until two successive readings are obtained which do agree to within 0.0001 + 10 per cent of the power factor.

APPENDIX II

PROPOSED METHODS OF TESTING ASKARELS[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. These methods of testing apply to askarels, synthetic nonflammable type insulating liquids which, when decomposed by the electric arc, evolve only nonexplosive gaseous mixtures.

NOTE.—Various materials have been used successfully in taking, storing, and testing samples of askarels. Until experience has developed a strong preference, materials referred to in these methods will be understood to be approved but not specified.

SAMPLING

General

2. Samples from shipments of askarels shall be taken in such a manner that they will be representative of the shipment. Samples from askarels in service shall be taken in such a manner that they will represent the portion of liquid in poorest condition.

Sampling Apparatus

3. (*a*) *General.*—Sampling apparatus shall be made of materials which will have no appreciable effect upon the test results. Approved materials are glass, stainless steel, or chromium-plated metal. Sampling apparatus shall be specially constructed for consistently withdrawing samples from various types of containers or electrical apparatus.

NOTE 1.—The sampler shown in Fig. 1 is so constructed that it may be used in taking either a top or a bottom sample. In either case the sample is released at the bottom of the sampler.

NOTE 2.—The sampler shown in Fig. 2 is of the cream dipper type. Liquid enters the dipper at the top and is released into the sample bottle by opening the valve at the bottom.

NOTE 3.—The sampler shown in Fig. 3 is of the vacuum type. It consists of a bottle fitted with a 2-hole cork stopper, glass tubing and a syringe bulb. Liquid is drawn through the glass tubing into the bottle by means of a partial vacuum produced by operation of the bulb.

(*b*) *For Drums.*—For sampling drums the apparatus shall be so designed that liquid will enter the top of the sampler cup when the cup is submerged approximately $\frac{1}{4}$ in.

NOTE 4.—A convenient and simple device for sampling drums is of the cream dipper type shown in Fig. 2.

(*c*) *For Cans.*—For sampling cans of 5-gal. capacity or larger an apparatus of the dipper type, Fig. 2 may be used, or an apparatus of the vacuum type shown in Fig. 3 may be used.

(*d*) *For Tank Cars.*—For sampling tank cars the sampling apparatus may be of the type shown in Fig. 1. This is a modification of the type shown in Fig. 2 of the Standard Methods of Testing Electrical Insulating Oils (A.S.T.M.

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[1] These proposed methods are under the jurisdiction of the A.S.T.M. Committee D-9 on Electrical Insulating Materials.

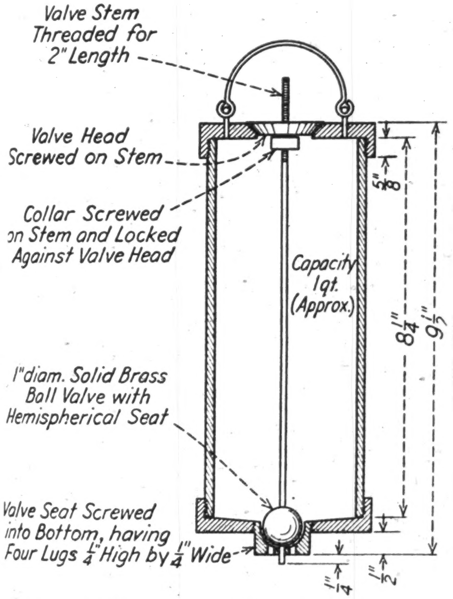
[2] Published as information, June, 1943; Revised, June, 1945.

Designation: D 117) of the American Society for Testing Materials.[3]

Sample Containers

4. (*a*) The following may be used as containers for the samples:

(*1*) Tin cans,
(*2*) Cork-stoppered or glass-stoppered dark-glass bottles, and
(*3*) Cork-stoppered or glass-stoppered clear-glass bottles in light-proof cartons.


Valve Stem Threaded for 2" Length
Valve Head Screwed on Stem
Collar Screwed on Stem and Locked Against Valve Head
Capacity 1qt. (Approx.)
1" diam. Solid Brass Ball Valve with Hemispherical Seat
Valve Seat Screwed into Bottom, having Four Lugs 1/4" High by 1/4" Wide
5/8"
8 1/4"
9 1/2"
1/4"
1/2"

NOTE.—Thief may be used for taking top or bottom sample from tank car. For bottom sample use as shown in sketch. For top sample screw valve head and collar about ¼-in. up on stem so that top valve remains fixed in open position, and submerge thief just below liquid level.

FIG. 1.—Sampler for Tank Cars.

NOTE.—The dark-glass bottle has the advantage that it protects the sample from the effects of bright light. The clear-glass bottle offers the advantage that it may be examined to see that it is clean. It also allows visual inspection of the liquid before testing, permitting the detection of free water or solid impurities.

(*b*) The containers shall be clean and dry. Samples placed in glass bottles shall be kept in the dark if subsequent testing is to include color, neutralization value, power factor or resistivity. For this reason light-proof cartons with covers shall be provided for each bottle into which the bottle with its sample of liquid shall be placed immediately after sampling. If cork stoppers are used they shall be covered with tin or aluminum foil. If glass-stoppered bottles are used, precaution shall be taken to insure that perfectly fitting stoppers are secured. A tin can fitted with a screw cap protected with a cork disk faced with tin or aluminum will endure harder usage. Tin cans shall be of the type having seams soldered on the exterior surfaces.

Cleaning of Sampling Apparatus and Sample Containers

5. (*a*) *General.*—All sampling apparatus and sample containers shall be cleaned thoroughly before using, special care being taken that no lint or other fibrous material remains in or on them. Care shall be taken to insure the complete removal of all traces of soldering flux from new containers.

NOTE.—Alcohol is a good solvent for soldering flux.

(*b*) *Sampling Apparatus.*—Sampling apparatus, before using, shall be cleaned by rinsing with dry, lead-free gasoline, Stoddard solvent, or carbon tetrachloride, and dried in the hot cabinet of the type described in Section 6 (*a*). The best procedure is to rinse it after the sampling has been finished and then place it in the hot cabinet, as in this way it will be ready for use without further cleaning when the next samples are to be taken. The rinsing material shall be used but once and then discarded.

(*c*) *Sample Containers.*—Sample containers, before using, shall be rinsed with lead-free gasoline and dried. They shall then be washed with strong soapsuds, rinsed thoroughly with distilled water and then dried by passing a current of dry, clean, warm air through the containers, after which they shall be immediately placed in the hot cabinet described in Section 6 (*a*). A similar washing will be sufficient for re-use of the containers that have held new liquid but those which have contained used liquid shall be washed with both lead-free gasoline and benzol before being washed with soapsuds.

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[3] 1944 Book of A.S.T.M. Standards, Part III.

Storage of Sampling Apparatus and Sample Containers

6. (*a*) *General.*—After cleaning and until required, all sampling apparatus and sample containers shall be kept in a dry, dust free, hot cabinet in which an air temperature of approximately 60 C. shall be maintained.

(*b*) *Sampling Apparatus.*—Sampling apparatus shall be kept at all times in a vertical position in the hot cabinet in a rack having a suitable drainage receptacle at the base.

(*c*) *Sample Containers.*—Containers for samples, after being washed and dried as described in Section 5 (*c*), shall be kept unstoppered while in the hot cabinet and shall be sealed immediately on removal. During the preparation and subsequent handling of the container when introducing the sample, care shall be taken that the operator's fingers do not touch the lip of the container.

Procedure for Sampling New Askarel

7. (*a*) It is recommended that 1 qt. of liquid be taken as a sample if complete physical and chemical tests are to be made and 1 pt. if only dielectric strength tests are to be made. Sample containers should not be completely filled, about 10 per cent of the volume being left for expansion.

(*b*) Samples shall not be taken from containers until the liquid is at least as warm as the surrounding air.

(*c*) Sample containers and sampling apparatus shall be rinsed with the liquid about to be sampled.

(*d*) Drums and cans shall be preferably sampled indoors and shall be kept undisturbed for at least 12 hr. before samples of liquid are taken.

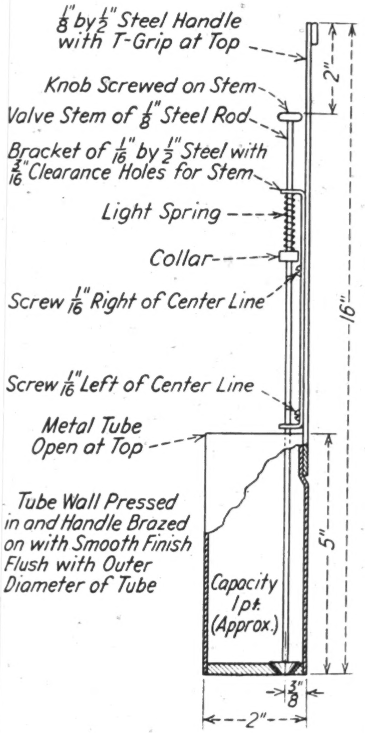
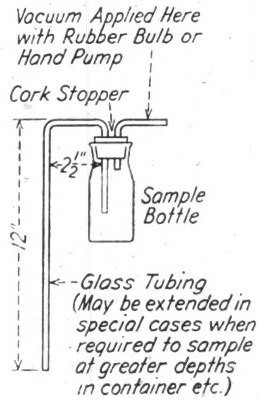

$\frac{1}{8}$" by $\frac{1}{2}$" Steel Handle with T-Grip at Top
Knob Screwed on Stem
Valve Stem of $\frac{1}{8}$" Steel Rod
Bracket of $\frac{1}{16}$" by $\frac{1}{2}$" Steel with $\frac{3}{16}$" Clearance Holes for Stem
Light Spring
Collar
Screw $\frac{1}{16}$" Right of Center Line
Screw $\frac{1}{16}$" Left of Center Line
Metal Tube Open at Top
Tube Wall Pressed in and Handle Brazed on with Smooth Finish Flush with Outer Diameter of Tube
Capacity 1 pt. (Approx.)
2"
16"
5"
$\frac{3}{8}$"
2"

FIG. 2.—Sampler for Drums.

(*e*) Drums of liquid to be sampled shall be lined up, preferably on their sides with their bungs up. The bungs shall be unsealed, removed and laid with the liquid contact sides up beside the bungholes. The dipper type sampler (Fig. 2) shall be lowered into the liquid until the lip of the cup is approximately $\frac{1}{4}$ in. below the surface of the liquid. When the sample has been transferred to the sample container, both the drum and the sample container shall be closed at once.

(*f*) When sampling containers such as cans of 5-gal. capacity or other small containers with the dipper type sampler (Fig. 2), the sampler shall be manipulated as in sampling drums or barrels. When using the vacuum type sampler (Fig. 3) the length of stem below the stopper shall be so adjusted that air bubbles are entrained as the sample is being drawn. This insures inclusion of a portion of the "surface layer." When the sample has been taken, the liquid container and the sample container shall be closed at once.


Vacuum Applied Here with Rubber Bulb or Hand Pump
Cork Stopper
2½"
12"
Sample Bottle
Glass Tubing (May be extended in special cases when required to sample at greater depths in container etc.)

NOTE.—In the case of samples for extremely sensitive tests such as power factor there is some evidence to indicate that brass or copper thiefs may affect the test results. The chemically clean glass thief is used to take samples for such tests from both 5-gal. cans and drums of new material. In special cases, it is used to sample apparatus in service.

FIG. 3.—Glass Sampler for Cans.

(*g*) Tank cars of liquid shall be sampled by means of a sampler of the type shown in Fig. 1. Both top and bottom samples shall be taken, as follows:

(*1*) In taking a top sample the upper valve head shall be so adjusted on the threaded shaft that it is held about $\frac{1}{4}$ in. above the top of the sampler. The sampler shall be lowered into the liquid so that the top is approximately $\frac{1}{4}$ in. below the liquid surface. The sample shall be transferred to the sample container by lifting the valve stem and so opening the lower valve.

(*2*) In taking a bottom sample the upper valve head shall be screwed down upon the collar in which position both valves remain closed until the stem is lifted. Displacement of air through the top valve largely prevents inflow of liquid through the top valve so that the sample is essentially a bottom sample. The sample container shall be stoppered immediately after it has been filled.

(*h*) When samples are being taken from different sources, precautions shall be taken to clean the sampler so as to prevent possible contamination of samples.

(*i*) Samples in either dark-glass or clear-glass bottles shall be stored in the dark.

Procedure for Sampling Liquids in Service

8. (*a*) It is recommended that 1 qt. of liquid be taken as a sample if complete physical and chemical tests are to be made and 1 pt. if only dielectric strength tests are to be made. Sample containers should not be completely filled, about 10 per cent of the volume being left for expansion.

(*b*) The precautions outlined in Sections 5 and 6 regarding the cleaning and storage of sampling apparatus and sample containers shall be observed as far as practicable.

NOTE 1.—As a precaution against moisture absorption, unnecessary exposure of askarel to the atmosphere should be avoided.

(*c*) Sample containers and sampling apparatus shall be rinsed with the liquid about to be sampled.

(*d*) The sampling of askarel in service is complicated by the fact that samples for electrical tests must be taken at the top surface of the liquid while samples for sediment must be taken from the bottom. Many transformers are equipped with a special sampling valve located just below the surface of the liquid. This valve terminates in a bent tube, open at the end, inside the transformer. This tube may be rotated about the horizontal center line of the valve as an axis, by a control knob on the outside of the transformer. The tube connects to an outlet on the outside of the transformer, the opening normally being capped. When not in use this tube is turned so that it points vertically upward. In this position the open end is above the surface of the liquid.

To take a sample the outside cap shall be removed and the tube rotated to a horizontal position. With the tube held in this position, just enough liquid shall be drawn off to flush the tube. This shall not be drawn into the sampling container. After the flushing, the tube shall be returned to the vertical position and the sample container substituted for the receptacle used for flushing. With the sample container held under the outlet, the tube shall then be turned until liquid just begins to flow freely through the tube. The tube shall be held in this position until a sufficient sample has been withdrawn; it shall then be returned to the vertical position.

NOTE 2.—In humid weather it is advisable to attach a metal fitting (cleaned as specified in Section 5) to extend from the valve into the sample container to prevent contamination of the sample by atmospheric moisture.

(*e*) Apparatus not equipped with special sampling valves may be sampled either by means of the dipper type sampler (Fig. 2) or the vacuum type sampler (Fig. 3). In using the vacuum type sampler, the end of the tube in the transformer shall be so adjusted that air bubbles are entrained as the sample is being drawn.

(*f*) Samples in either dark-glass or clear-glass bottles shall be stored in the dark.

SPECIFIC GRAVITY

Definition

9. The specific gravity of askarels is the ratio of the weight of a given volume of the material at a temperature of 60 F. (15.56 C.) to the weight of an equal volume of distilled water at the same temperature, both weights being corrected for the bouyancy of air.

Apparatus

10. (*a*) *Hydrometer.*—A hydrometer of the conventional floating glass type, calibrated in terms of specific gravity shall be used. The range of the instrument shall be any suitable portion of the interval between 1.0000 and 2.0000, with the scale divided in 0.001 of a unit of specific gravity, and the scale divisions spaced not less than 0.75 mm. (0.03 in.) nor more than 1.5 mm. (0.06 in.) apart. The scale shall be so marked that it can be easily read, and the accuracy of the calibration of the hydrometer shall be such that the error at any point of the scale shall not exceed 0.0005.

(*b*) *Hydrometer Cylinder.*—The receptacle in which the liquid is tested shall be a cylinder made of clear glass. The inside diameter of the cylinder shall be at least 2.54 cm. (1.0 in.) greater than the outside diameter of the hydrometer and the height of the cylinder shall be such that the column of liquid under test exceeds by at least 2.54 cm. (1.0 in.) the submerged portion of the hydrometer after a state of equilibrium has been reached.

(*c*) *Thermometer.*—An A.S.T.M. thermometer of the total immersion type and conforming to the requirements prescribed in the Standard Specifications for A.S.T.M. Thermometers (A.S.T.M. Designation: E 1),[3] shall be used in taking the temperature of the liquid under test.

(*d*) *Temperature-Control Apparatus.*—Suitable apparatus shall be provided for controlling the temperature of the liquid under test to 60 ± 1 F (15.56 ± 0.56 C.). This may consist of a liquid bath, into which the hydrometer cylinder is placed, or a conditioning chamber in which temperature-controlled air is the regulating medium.

Procedure

11. (*a*) The measurement of specific gravity shall be made at a temperature of 60 F. (15.56 C.). The sample to be tested shall be poured into the clean hydrometer cylinder without splashing, so as to avoid, as much as possible, the formation of air bubbles. If air bubbles are formed, they shall be removed after they have collected on the surface by touching them with a piece of clean blotting or filter paper before the hydrometer is placed in the sample. The hydrometer and thermometer shall then be placed in the liquid and the cylinder placed in the conditioning medium and kept there until the required temperature of sample as indicated by the thermometer, is reached. An occasional gentle stirring will facilitate reaching the desired temperature. If a liquid bath is used, the apparatus should be set up in a location as free from air currents as possible. If an air conditioning chamber is used, any fans used for air circulation shall be shut off as soon as the test temperature is reached, so that disturbance from air currents will be minimized.

(*b*) When the liquid under test has reached the test temperature, the hydrometer shall be raised slightly and the stem carefully wiped clean, after which it shall be lowered slowly into the sample to a level of two smallest scale divisions below that at which it will float, and shall then be released. When the hydrometer has come to rest, floating freely away from the walls of the cylinder, the specific gravity shall be read and recorded. In the case of transparent liquids, the hydrometer shall be read with the eye at the level of the surface of the liquid and at the point where the bottom of the meniscus of the liquid intersects the hydrometer scale. In the case of nontransparent liquids, the hydrometer shall be read at the highest point on the scale to which the liquid rises. This reading shall then be corrected by an amount equal to the height to which the liquid rises on the hydrometer scale above the main surface of the sample.

(*c*) The thermometer in the sample shall be read immediately after the specific gravity is determined.

Reproducibility of Results

12. (*a*) Duplicate determinations shall agree within 0.001 unit of specific gravity when the same hydrometer and thermometer are used in the tests.

(*b*) Separate laboratories using different hydrometers and thermometers should obtain duplicate results, agreeing within 0.002 unit of specific gravity.

COLOR

Preparation of Reference Standards

13. (*a*) Dissolve 1.245 g. of potassium chloroplatinate (K_2PtCl_6) containing 0.5 g. of platinum, and 1 g. of crystallized cobaltous chloride ($CoCl_2 \cdot 6H_2O$) containing about 0.25 g. of cobalt in water with 100 ml. of HCl (sp. gr. 1.18). Dilute to 1 liter with distilled water. This solution has a color of 500.

(*b*) To prepare reference standards having colors of 5, 10, 15, 20, 25, 30, 35, etc., dilute 0.5, 1.0, 1.5 ml., etc., of the solution prepared as described in Paragraph (*a*) with distilled water to 50 ml. in 50-ml. tall-form Nessler tubes. Protect the reference standards from evaporation when not in use.

(*c*) The unit of color is that color produced by 1 mg. of platinum per liter.

Procedure

14. (*a*) The color of the sample shall be observed by filling a matched Nessler tube to a height equal to that in the reference standard tubes with the liquid to be examined and comparing it with the reference standards. The determination shall be made by looking vertically downward through the tubes upon a white or mirrored surface placed at such an angle that light is reflected through the columns of liquids.

(*b*) This method is good only up to a color intensity of about 100. For reading higher values the sample should be diluted with water-white benzol and the color obtained by multiplying by the dilution ratio.

Recording Colors

15. Colors between 1 and 100 shall be recorded to the nearest 5. Colors between 101 and 300 shall be recorded to the nearest 10. Colors above 300 shall be recorded in accordance with the Tentative Method of Test for Color of Lubricating Oil and Petrolatum by Means of A.S.T.M. Union Colorimeter (A.S.T.M. Designation: D 155) of the American Society for Testing Materials.[4]

VISCOSITY

Procedure

16. Viscosity shall be determined in accordance with either the Standard Method of Test for Viscosity by Means of the Saybolt Viscosimeter (A.S.T.M. Designation: D 88)[3] or the Tentative Method of Test for Kinematic Viscosity (A.S.T.M. Designation: D 445)[3] of the American Society for Testing Materials and, unless otherwise specified, at a temperature of 37.8 C. (100 F.).

FIRE POINT

Procedure

17. Askarels as such have no fire point. As a test for appreciable contamination by flammable liquids the lack of a fire point shall be verified in accordance with the Standard Method of Test for Flash and Fire Points by Means of Open Cup (A.S.T.M. Designation: D 92) of the American Society for Testing Materials.[4] The verification temperature shall be 200 C. (392 F.).

POUR POINT

Procedure

18. Pour point shall be determined in accordance with the Standard Method of Test for Cloud and Pour Points (A.S.T.M. Designation: D 97) of the American Society for Testing Materials.[3]

NEUTRALIZATION NUMBER

Procedure

19. Neutralization number shall be determined in accordance with the Tentative Method of Test for Acid and Base Numbers of Petroleum Products by Color-Indicator Titration (A.S.T.M. Designation: D 663) of the American Society for Testing Materials.[3] Neutralization number may also be determined in accordance with the Tentative Method of Test for Acid and Base Numbers of Petroleum Products by Electrometric Titration (A.S.T.M. Designation: D 664)[3] if it is desired to use an electrometric titration method.

FREE CHLORIDES

Nature of Test

20. This method applies to the quantitative determination of the free chlorides in askarels.

Extraction of Chlorides

21. (*a*) A 50-ml. sample of askarels shall be heated to 90 to 100 C. (194 to

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[4] 1945 Supplement to Book of A.S.T.M. Standards, Part III.

212 F.), placed in a chemically clean 100-ml. separatory funnel and extracted with two portions of hot (90 to 95 C. (194 to 203 F.)) chloride-free distilled water. The total weight of water shall be equal to that of the 50 ml. of askarel tested. The first extraction shall be made using approximately two thirds of the water. The second extraction shall be made using the remaining one third of the water.

(*b*) Extraction shall be made by stoppering the funnel and shaking the askarel-water mixture vigorously for a minimum of 20 sec. After allowing to settle, the water extracts shall be separated into a clean centrifuge flask. The first and second extracts shall then be combined and mixed thoroughly.

(*c*) The combined water extracts shall be centrifuged until the water shows a negative Tyndall beam effect.

Apparatus

22. (*a*) *Burette.*—A 10-ml. burette graduated in subdivisions not greater than $\frac{1}{20}$ ml.

(*b*) *Evaporating Dish.*—A clean white porcelain evaporating dish of at least 150-ml. capacity.

Reagents

23. (*a*) *Standard Sodium Chloride Solution.*—Dissolve 0.824 g. of pure fused sodium chloride in distilled water and make up to 1 liter. Dilute 100 ml. of this solution to 1 liter. One milliliter of this dilute solution contains 0.05 mg. of chloride radicle. Distilled water shall be chlorine free.

(*b*) *Standard Silver Nitrate Solution.*—Dissolve about 0.24 g. of silver nitrate crystals in 1 liter of distilled water. Titrate against the above standard sodium chloride and adjust silver nitrate solution so that 1 ml. will be exactly equivalent to 0.05 mg. of chloride radicle.

(*c*) *Potassium Chromate Indicator.*—Dissolve 50 g. of neutral potassium chromate in a little distilled water. Add silver nitrate to produce a slight red precipitate. After a day or two, filter and dilute the filtrate to 1 liter with distilled water.

Procedure

24. Prepare a solution for the purpose of color reference by adding 1 ml. of chromate indicator to 50 ml. of distilled water in a clean evaporating dish, and titrate with the standard silver nitrate, adding the solution drop-by-drop while stirring constantly until a very slight reddish tinge, when compared with the reference standard, is produced that will persist for several minutes. The end point is very sharp if the test is performed in a darkened room provided with a yellow light.

NOTE.—In case the chloride content is less than 5 ppm. a large amount of askarel should be treated to give 100 ml. of water extract for test and the proper factor applied.

Report

25. The chloride content shall be reported in parts per million which is numerically equal to the milliliters of silver nitrate used in the test.

ARC-FORMED GASES

Apparatus

26. The apparatus shall consist of the following:

(*a*) *Glass Container.*—A glass container of not less than 2-oz. capacity, fitted with suitable electrodes and outlet for gases.

(*b*) *Glass Tube.*—Glass tube filled with lightly-packed glass wool for removal of carbon particles from gases of decomposition.

(*c*) *Graduated Container.*—Graduated container for collection of gases by displacement of a suitable liquid.

(*d*) *Gas Apparatus.*—An Orsat or Burrell apparatus for analysis of the gases.

Procedure

27. (*a*) Any convenient glass vessel fitted with electrodes may be used. A suitable set-up has been made using for the sample holder a 2-oz. screw-cap type bottle fitted with a rubber stopper with two brass electrodes ($\frac{1}{8}$ to $\frac{1}{4}$-in. rod) and a glass tube outlet for the gases. Arc-formed gases shall be led (in series with the glass wool filter) to the gas collection and measuring burette. After clamping in place, the vessel shall be filled to three fourths of its capacity with the liquid to be arced.

(*b*) Electric current (110 v.d.c.) shall then be connected externally to the electrodes. The line should contain a resistance of 4 to 5 ohms. Arcing shall be carried out by manual make-and-break of the electrodes in the liquid. The external portion of the electrodes should be insulated.

(*c*) Analysis of the sample for carbon dioxide, unsaturated hydrocarbons, oxygen, carbon monoxide, saturated hydrocarbons, and hydrogen shall be carried out in the usual manner.

(*d*) The gas shall first be collected over trichlorbenzene or carbon tetrachloride which has been saturated with hydrogen chloride gas. The first absorption pipette of the gas analyzer shall then be filled with water and the halogen-containing gas determined by the percentage of gas absorbed at this stage. The residue shall then be submitted to the regular analysis for the gases previously mentioned. In order that no combustible gases may pass undetected, the explosion test for hydrogen and the saturated hydrocarbons should be carried out with oxygen.

Precautions

28. (*a*) Before collecting gases for analysis, the connecting tubing of the apparatus shall be flushed out using a total of not less than 100 ml. of the arc-formed gases.

(*b*) Check tests shall be made on fresh samples of the liquid.

REFRACTIVE INDEX

Apparatus

29. The apparatus shall consist of the following:

(*a*) *Refractometer*.—An Abbé refractometer with scale graduated directly in terms of refractive index of the D line of sodium at a temperature of 20 C.

(*b*) *Water Supply*.—A water supply which may be varied as to temperature.

Procedure

30. (*a*) The refractometer shall be placed in front of a suitable source of light (either daylight or electric light), the thermometer inserted and circulation of water adjusted so as to bring the prisms to the desired temperature (usually 20 C.). A drop of the liquid to be tested shall then be spread upon the upper prism after which the lower prism shall be turned over and clamped. The mirror shall then be adjusted so that the light enters the telescope. The eyepiece shall be focussed on the cross-hairs and the reading lens on the scale. Upon moving the prism arm, a position can now be found where the lower part of the field is dark and the upper part light. In general, the border line will be colored and this is corrected by turning the milled head on the right of the telescope so that a sharp black and white edge is obtained. The prism arm is now moved until this black edge just crosses the intersection of the cross-hairs. The refractive index shall then be read off on the scale, the fourth decimal place being estimated.

(*b*) The accuracy of the instrument may be checked by a small test plate of known refractive index which is supplied with the refractometer. This test plate shall be attached to the upper prism with a liquid of high refractive index (usually mono-brom naphthalene). Errors may be corrected by means of a small adjusting screw on the back of the telescope.

DIELECTRIC STRENGTH

NOTE.—A method for determining dielectric strength of askarels is in preparation by the committee. Meanwhile, reference should be made to the method of test for liquid dielectrics in the Standard Methods of Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (A.S.T.M. Designation: D 149).[3]

POWER FACTOR

NOTE.—A method for determining power factor of askarels is in preparation by the committee. Meanwhile, reference should be made to the method of test for liquids in the Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (A.S.T.M. Designation: D 150).[4]

APPENDIX III

REPORT ON RESULTS OF QUESTIONNAIRE TO UTILITIES RELATING TO TESTS ON TRANSFORMER OIL IN SERVICE

Report of Subcommittee IV on Insulating Liquids

October 12, 1945

At the meeting in Philadelphia, Pa. on February 22, 1944, of Subcommittee IV on Insulating Liquids, of A.S.T.M. Committee D-9 on Electrical Insulating Materials, it was decided to send a questionnaire to utility companies requesting data and information regarding their tests and procedures in appraising the serviceability of oil in transformers in service. Suggestions were offered by the chairman and other committee members to outline some of the principal questions generally regarded as most pertinent, in determining just which tests are used by various companies as criteria of serviceability and the ranking of these tests as to their relative importance. Special emphasis was given to the purpose of determining the importance attached to the test for dielectric strength and whether the sludging of transformer oil is a very serious problem at the present time.

In accordance with this general advice and subsequent more direct assistance by F. M. Clark, a questionnaire was prepared by the undersigned and mailed April 28, 1944, to 92 electric utility companies in the United States. The mailing list included the larger utilities and a special effort was made to get wide distribution geographically. An index of the various companies who replied is listed alphabetically in Table I.

The questionnaire in condensed arrangement was presented as follows:

Question I.—Please list in the order of their relative importance, the tests that you consider to be significant in testing transformer oil in service to judge its suitability for continued use.

Question II.—Just which tests do you always make on the oil to appraise its serviceability and what is your allowable limit for each test?

Question III.—Do you make these tests periodically at a fixed time interval? If so, what is the time interval?

Question IV.—What supplementary tests do you sometimes make in addition to those noted under Question II to judge serviceability and what is the allowable limit for each?

Question V.—What tests have you investigated in the past and abandoned as not being worth continuing?

Question VI.—In general, is the sludging of oil a serious problem today? Give further information if possible, regarding: Approximate date of manufacture of transformers where excessive sludging occurs; average load of such transformers (in per cent of normal); types of construction (that is, "open breather," "conservator," or "sealed"); and what steps are taken to reduce or eliminate cases of excessive sludging.

The first progress report and summary of results was made to Subcommittee IV at the meeting on June 29, 1944, in New York, N. Y. At this date, a total of 53 replies had been returned. In accordance with the suggestion of various committee members and the chairman, a follow-up letter was sent out early in August to stimulate replies from those who had failed to answer. The ultimate total of replies reached the figure of 67, or approximately 73 per cent of all companies contacted.

Obviously, the nature of the data and other information is such that a simple statistical analysis is not possible. Therefore an attempt has been made to summarize briefly the answers to each question in Table II (Plate V).[1] This table in itself is considered to be the principal part of this report. It is the most useful and comprehensible form in which to show the results. However, the following notes under Questionnaire Analysis are added in amplification of the summary in Table II.

QUESTIONNAIRE ANALYSIS

Question I (Tests Made and Order of Importance):

One of the most striking features of the answers to Question I is that 62 out of 67 companies place the test for dielectric strength in first place as to importance. However, a significant number qualify this ranking of the dielectric test. The overall concensus appears to be generally consistent with the following statements: (*1*) The dielectric test serves a very important function as an index of serviceability; (*2*) With particular reference to frequency of use of a given test, the dielectric test would be ranked first, but so far as intrinsic quality or stage of deterioration is concerned, other tests also are very essential. However, beyond the statement of the fact that the dielectric test is generally ranked first, any further attempt to rank the various tests listed as to relative importance appears to resolve itself into an absurdity.

The numerical sequence 1, 2, 3, 4, etc., to indicate order of importance is not used in a consistent manner by all recipients. For example, one company might list the dielectric test, a sludge content, and color test as three tests under numbers 1, 2, and 3, respectively, as tests of first importance with other tests following in regular sequence, while another company might group all of these tests under number 1 with additional tests under 2, 3, 4, etc. The greatest significance should be attached to the matter of just which tests are listed as having importance. These are summarized as follows: All of the 67 questionnaires listed the dielectric test; 58 out of 67 listed neutralization number; 38 noted the color test and visual inspection for sludge or sediment; 22 noted the power factor test; 4 mentioned steam emulsion; and 4 interfacial tension.

Question II (Tests Always Made and Allowable Limits):

All companies, without exception, noted the test for dielectric strength as one test which was always made to judge serviceability. The minimum limits set for the breakdown value range between 16.5 and 33 kv. The limiting values of 20, 22, or 25 kv. appear to be the most commonly used. However, a minimum limit of 16.5 or 17 kv. is applied by the Boston Edison, Consolidated Edison of New York, Dallas Power and Light, Memphis Light, Gas and Water Division, New Orleans Public Service, Inc., Oklahoma Gas and Electric, and Pennsylvania Power and Light Co. A minimum limit of 17.5 or 18 kv. is used by the Detroit Edison, Nebraska Power Co., Duquesne Light Co., Chicago District Electric Generating Corp., and the Commonwealth Edison Co. Values for new oil or reclaimed oil are generally set higher than for oil in service. (Whenever the electrodes for the dielectric strength test were defined, 1-in. diameter disks with 0.1-in. gap invariably were stipulated. It was as-

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[1] This plate appears in envelope on inside back cover.

TABLE I.—ALPHABETIC LIST OF COMPANIES WHO RETURNED QUESTIONNAIRE.

	Company	Answered By
No. 28	Alabama Power Co., Birmingham, Alabama	C. B. Hawkins, Superintendent of Transmission W. H. McClure
No. 49	Boston Edison Co., Boston, Mass.	R. W. Chadbourn, Committee Member
No. 43	Buffalo Niagara Electric Corp., Buffalo, N. Y.	N. B. Phillips, Superintendent Meters and Services
No. 66	Carolina Power and Light Co., Raleigh, N. C.	A. M. McCabe, Substation and Valley Superintendent
No. 54	Central Illinois Light Co., Peoria, Ill.	R. D. Hart, Superintendent Electric Meter Department
No. 16	Central Illinois Public Service Co., Springfield, Ill.	H. E. Stites, Electrical Engineer
No. 36	Central New York Power Corp., Syracuse, N. Y.	J. L. Welch
No. 31	Chicago District Electric Generating Corp., Hammond, Ind.	C. T. Hesselmeyer T. C. White
No. 34	Cincinnati Gas and Electric Co., Cincinnati, Ohio	S. M. Hamill Jr., Assistant Superintendent Electric Operating Department
No. 47	Cleveland Electric Illuminating Co., Cleveland, Ohio	F. Borch, Electrical Engineer
No. 13	Columbus and Southern Ohio Electric Co., Columbus, Ohio	C. D. Price, Electrical Engineer
No. 37	Commonwealth Edison Co., Chicago, Ill.	L. B. Schofield, Materials Engineer
No. 3	Connecticut Light and Power Co., Waterbury, Conn.	C. T. Hughes, General Superintendent
No. 39	Consolidated Edison Co. of New York, New York, N. Y.	C. T. Hatcher, Acting Division Engineer
No. 46	Consolidated Gas, Electric and Power Co. of Baltimore, Md.	E. F. Wolf, Assistant to Superintendent Electric Test Department
No. 57	Consumers Power Co., Jackson, Mich.	F. G. Boyce, Vice-President
No. 8	Dallas Power and Light Co., Dallas, Texas	T. M. Northum, Operating Division Head
No. 50	Detroit Edison Co., Detroit, Mich.	E. C. DeBaene, Committee Member
No. 58	Duquesne Light Co., Pittsburgh, Pa.	E. R. Whitehead, Investigating Engineer
No. 52	Georgia Power Co., Atlanta, Ga.	
No. 19	Gulf States Utilities Co., Beaumont, Texas	E. C. Adams, System Electrical Engineer
No. 2	Hartford Electric Light Co., Hartford, Conn.	C. L. Derrick, Engineer
No. 7	Houston Lighting and Power Co., Houston, Texas	
No. 48	Hydro-Electric Power Commission, Toronto, Ont., Canada	H. J. Muehleman, Chief Operating Engineer W. P. Dobson, Director of Research
No. 26	Idaho Power Co., Boise, Idaho	B. C. Russell, General Superintendent
No. 53	Indianapolis Power and Light Co., Indianapolis, Ind.	H. P. Cox, Assistant Superintendent Electrical Department
No. 4	Jersey Central Power and Light Co., Asbury Park, N. J.	L. C. Van Inwegen
No. 24	Kansas Gas and Electric Co., Wichita, Kansas	C. V. Waddington, Engineer
No. 20	Kentucky Utilities Co., Lexington, Ky.	T. M. Fleming, Electrical Engineer
No. 45	Long Island Lighting Co., Mineola, N. Y.	H. J. DeBaun, Manager Electric Transmission and Distribution
No. 1	Los Angeles Department of Water and Power, Los Angeles, Cal.	T. M. Blakeslee, Superintendent Testing Lab.
No. 10	Memphis Light, Gas and Water Div., Memphis, Tenn.	C. A. Reitz, Supervisor, Electric Repair Department
No. 9	Metropolitan Edison Co., Reading, Pa.	H. M. Rankin, Chief Engineer
No. 25	Montana Power Co., Butte, Mont.	C. R. Davis
No. 21	Nebraska Power Co., Omaha, Neb.	I. H. McNeil, Superintendent of Distribution
No. 51	New England Power Assn., Boston, Mass.	E. F. Walsh, Assistant to Superintendent Power Station
No. 5	New Orleans Public Service, Inc., New Orleans, La.	L. L. Newman, Superintendent of Distribution
No. 14	Northern Indiana Public Service Co., Hammond, Ind.	A. D. Therrien, General Foreman Substations
No. 59	Ohio Edison Co., Akron, Ohio	F. W. Funk, Chief Engineer
No. 35	The Ohio Power Co., Canton, Ohio	R. R. Krammes, Superintendent of Substations
No. 55	Ohio Public Service Co., Elyria, Ohio	L. F. Ferri, Electrical Engineer
No. 33	Oklahoma Gas and Electric Co., Oklahoma City, Okla	L. M. Limpus, Superintendent Testing andRepair Department
No. 11	Pacific Gas and Electric Co., San Francisco, Cal.	C. E. Baugh
No. 67	Pennsylvania Electric Co., Johnstown, Pa.	D. R. Pattison, Electrical Engineer
No. 23	Pennsylvania Power and Light Co., Allentown, Pa.	L. J. Gill, Assistant to Superintendent Lines and Substation.
No. 29	Philadelphia Electric Co., Philadelphia, Pa.	P. H. Chase
No. 60	Portland General Electric Co., Portland, Ore.	Delmar Brown, Chemist C. A. Warren, In Charge, Transformer Department
No. 63	Potomac Electric Power Co., Washington, D. C.	T. C. Pearce, Superintent of Substations
No. 56	Public Service Co. of Colorado, Denver, Colo.	W. D. Hardaway, Superintendent Hydro-Electric Production and Transmission
No. 42	Public Service Co. of Northern Illinois, Chicago, Ill.	H. A. Cornelius, Senior Engineer
No. 65	Public Service Electric and Gas Co., Newark, N. J.	John S. Ware, General Superintendent of Distribution, Electric Department
No. 18	Rochester Gas and Electric Corp., Rochester, N. Y.	H. J. Klumb, Superintendent Electric Distribution
No. 64	San Diego Gas and Electric Co., San Diego, Cal.	K. F. Williamson, Superintendent Tests and Inspection; J. B. Bowen, Supt. Electric Repair Division
No. 38	Southern California Edison Co., Los Angeles, Cal.	L. H. Beebe, Superintendent Shop and Test Division
No. 61	Tennessee Valley Authority, Wilson Dam, Tenn.	J. F. Gordon, Superintendent Maintenance Division
No. 6	Toledo Edison Co., Toledo, Ohio	
No. 32	Union Electric Co. of Missouri, St. Louis, Mo.	R. C. Morris, System Distribution Engineer
No. 27	United Illuminating Co., New Haven, Conn.	W. A. Upham, General Superintendent Distribution

TABLE I.—ALPHABETIC LIST OF COMPANIES WHO RETURNED QUESTIONNAIRE.—*Continued*

	Company	Answered By
No. 17	United States Bureau of Reclamation, Denver, Colo.	L. N. McClellan, Chief Electrical and Mechanical Engineer
No. 41	Utah Power and Light Co., Salt Lake City, Utah	T. A. Purton, Chief Engineer
No. 15	Virginia Electric and Power Co., Richmond, Va.	F. W. Smith, Manager of Engineering
No. 40	Westinghouse Electric Corporation, Pittsburgh, Pa.	T. K. Sloat, Research Engineer
No. 30	West Penn Power Co., Pittsburgh, Pa.	O. E. Fawcett, Committee Member
No. 12	Wisconsin Electric Power Co., Milwaukee, Wis.	W. E. Gundlach, Chief Electrical Engineer
No. 22	Wisconsin Power and Light Co., Madison, Wis.	T. N. Langum, Superintendent Operation and Maintenance
No. 62	Wisconsin Public Service Corp., Milwaukee, Wis.	H. P. Taylor, Vice-President and Treasurer

sumed that all the test limits noted refer to electrodes of this standard size and spacing.)

Approximately 30 of the 67 answers list the acidity test as one regularly made although in most cases special notes indicate that this test would be made only when other conditions attracted attention such as color, sludge, and operating temperature, or in the case of transformers of the higher voltage ratings. Maximum limits established for acidity range between 0.15 and 1.65 mg. of KOH per gram of oil. The limits most commonly stated tend to fall between 0.7 and 1.0 mg. of KOH per gram of oil for oil in service. See also statement under Question IV below.

Ten of the 67 returned questionnaires list power factor as a routine test although it appears that the same conditions in deciding to make this test apply here as to the neutralization value. Maximum limits for power factor, when stated, vary from 1.0 to 3.0. However, these values have limited significance without test temperatures and other conditions stated.

Two companies mention the steam emulsion test (S.E. No.) as a routine test regularly made and two include interfacial tension. See also statement under Question IV below.

Question III (Time Interval for Periodic Tests):

The intervals used by various companies for periodic tests vary considerably between 1 month and 2 yr., depending on classes of service, voltage rating, and other arbitrary classifications. The most common interval appears to be either 3, 6, or 12 months. Shorter intervals of 1 to 3 months are often stipulated for transformers of the higher service voltages or water-cooled equipment. The most comprehensible method of gaining information on this question is by direct reference to the summary in Table II.

Question IV (Supplemental Tests and Allowable Limits):

It would appear from close scrutiny of the answered questionnaires that in many cases where certain tests might have been listed here, they were listed under Question II, virtually as tests that could be considered supplementary to the dielectric test and visual observations. For this reason the answers to Questions II and IV are considered together in the following statements:

Sixty out of the 67 answered questionnaires list the acidity test as *either* a routine periodic test or supplementary test when other conditions seem to justify closer analysis of stage of deterioration.

Twenty-two of the 67 answers list power factor; 6 of the 67 answers note steam emulsification (S.E. No.), and 6 mention interfacial tension as either a periodic or possible supplementary test.

Question V (Tests Used in Past, Now Abandoned):

It is somewhat superfluous to attempt to amplify the answers to this question as to the tests used in the past and since abandoned. Analysis of the answers may be made by direct reference to the summary in Table II.

Question VI (Is Sludging Considered Serious Problem Today):

The answers to this question as to whether sludging of oil is a serious problem at present are generally negative, with special notes in most cases to qualify the answer. Even in the cases where the answer is "yes," there is a remarkable consistency in the special amplifying notes showing essential agreement with the negative answer if certain exceptions are granted. Practically all of the answers would be in agreement with the following broad statement: Sludging is not appreciable in modern transformers of the conservator or gas-sealed type, but may be a serious problem in older transformers of the open-breather type, particularly those carrying heavy loads. (Many replies include a comment that there is a substantial proportion of older transformers with open breathers now in service.)

Wherever sludging is encountered, serious trouble is avoided by keeping diligent watch on the oil and establishing limiting values for sludge content, neutralization value or other properties used as criteria of serviceability. (See Questions II and IV.) Also temperature and loading conditions are significant factors. When the degree of sludging or aging has exceeded the limits to be tolerated, some companies make it a practice to reclaim the oil by filtration and deacidifying treatment; others replace the sludged oil with new oil.

At this point, a supplementary question arises as to how many companies accept the general practice of reclaiming a *sludged oil* once it has been condemned for further service. (In general this refers to oils of high acid value.) This question was not directly stated in the questionnaire and therefore the answer is available in only a limited number of the replies. In those cases where the answer was given directly or could be deduced with reasonable certainty from miscellaneous appended remarks, it is noted in the appropriate column of Table II. Otherwise the space is left blank.

Fifteen companies of 26 answering this question, or roughly 60 per cent, apparently follow a practice of reclaiming oil.

The above comments with the summary in Table II provide a brief analysis of replies so far as the main components of Question VI are concerned. However, the questionnaire carried a request for supplementary information regarding the sludging problem in general. Some of the replies included comments of a very copious nature while others were comparatively brief. All of this information is considered quite timely and pertinent but somewhat beyond the scope of this report to discuss in any detail. Wherever possible the comments are abstracted in Table II in such form as to retain their full significance. In all cases where this is not possible, the complete comments (with few exceptions) are quoted in the Appendix which comprises quite an important supplement to this report.

One feature of the detailed comments received under Question VI, as well as some of the other questions which should be regarded as significant, is the emphasis generally placed on acidity and its relation to sludging and serviceability of a used oil. Many companies have no fixed limit established for acidity of an oil from transformers in service but this matter is being given considerable attention at present. There is a pronounced trend toward a policy which would adopt a maximum limit for acidity, below which deterioration of the solid insulation would be nearly negligible, then maintain the acidity below this level for the life of a transformer. What the true value of this limit should be has not been very definitely established. In the end, a rigid control of oil acidity should be much less costly than unchecked deterioration of the insulation in large power transformers.

APPENDIX

COMMENTS OF VARIOUS COMPANIES MADE UNDER QUESTION VI OF THE QUESTIONNAIRE

9. *Metropolitan Edison Co.*—Example: Sludging in three 3333 kva., water-cooled transformers made in 1917; average load 70 per cent; open breather. Installed conservators. In some cases old breathers are replaced with increased number of newer type. Uniflow air circulation system also installed on transformers with open breathers to eliminate condensation on underside of cover.

15. *Virginia Electric and Power Co.*—All new power transformers of 1000 kva. and larger purchased with activated alumina or silica-gel breathers. We have added this type of breather to old transformers on the system. Conservators normally required on transformers of 1000 kva. and above with breathers. Smaller transformers have been purchased completely sealed.

17. *U. S. Bureau of Reclamation.*—In this case a very interesting bulletin was submitted with the title "Maintenance of Mineral Insulating Oils; Power O. & M. Bulletin No. 11." As stated in the preface, it is the purpose of this bulletin to give a better understanding of how insulating oil is affected by moisture and oxidation, and to establish a uniform maintenance practice for testing and purifying insulating oils. One section of the bulletin deals with the subject of oxidation and its relation to acidity and sludge in oil. This section includes useful test data showing the relation of acidity to oxygen absorbed by the oil and practical conclusions from this data to estimate the life of an oil (prior to sludging) in transformers with various types and degrees of sealing. Also, information on purifying procedures is given in this bulletin. An abstract of the section of this bulletin dealing with oxidation, acidity, and sludging is given as follows:

The measurement of acidity of an oil is considered to be the most reliable indicator of the extent of oxidation, since some of the products of oxidation are of an acid nature. When sludging has progressed to the point where it covers the core and windings, the first step should be to remove the sludge by a high-pressure stream of oil and to either replace the oil, or treat it with activated clay to remove the acid.

The best plan for determining the extent of oxidation is to make acidity tests from time to time, so it can be determined when the oil should be treated before it reaches the sludge forming stage..... Sludging has been found to begin when the acidity reaches a neutralization number of roughly 0.4 to 0.5 mg. of KOH per gram of oil.

When it has been determined by the neutralization number that the oil is approaching the point at which sludging may start, the oil should be treated by the Fuller's earth (activated clay), activated alumina, or some other approved method for reducing acidity. Removal of sludge from oil may be done with a blotter filter press, but the acid is not removed by this process and sludge would promptly form again since the conditions for the formation of sludge have not been removed. The Denver Office is investigating commercial equipment for treating oil with activated clay to remove acidity. The process in general is to first filter the oil to remove water and other impurities, then to pass the oil through a quantity of activated clay or to mix clay in the oil, then to pass the oil through a filter press to remove the clay and other impurities. Heating the oil helps to make the clay more effective in removing acid and improving color. It is expected that it will be possible to keep the transformer in service, where necessary, while the oil is being treated.

Tests have been made which indicate that acidity is proportional to the amount of oxygen absorbed by the oil. It is estimated that 0.2 cu. ft. of oxygen absorbed per gallon of oil will cause an acidity of about 0.5 mg. of KOH, which is the approximate neutralization number at which sludging is assumed to start. On the basis of this and other assumptions, it has been estimated that different types of transformers would take the following periods of time before sludge would appear on the basis of equal loading test cycles:

Transformer with free air access....	1.5 yr.
Transformer with conservator......	4 to 7 yr.
Transformer bolted up tight........	50 yr.
Transformer with nitrogen over oil..........................	67 yr.

While the above periods may not correspond to actual field examples due to different load conditions from those assumed, the relative length of the periods for the different types of transformers may be comparable, and is of interest.

19. *Gulf States Utilities Co.*—Sludging is more active in transformers loaded 115 to 130 per cent than with lesser loads; more active in open-breather than conservator or sealed type. Load is reduced if sludging is caused by overload. Oil changed if sludging has progressed to any extent.

Much sludging in transformers of *open-breather* type of three makes delivered from 1925 to 1930. These showed excessive sludge in 1935 causing some failures before detection.

Other transformers of *conservator type* purchased in 1925 had oil replaced in 1943 and 1944.

Large transformers with *inert gas seal*, on system since 1925 have not shown any signs of oil deterioration.

The replacement of transformer oil can best be decided on an acidity basis. Found from experience with great number of cases when neutralization number exceeds 0.2, sludge is likely to begin. Acidity increases at very accelerated rate after reaching this point. When neutralization number reaches 0.5 or 0.6, sludging is quite rapid and there is a pronounced change in color from light straw to very dark color. Certainly any oil with a neutralization number of 0.6 or over should be replaced.

We have found it is not sufficient in such cases merely to replace oil in these transformers without thoroughly cleaning the core and coils as it is very difficult to flush these transformers entirely free of sludge. Apparently very small amount of sludge in transformer provides reagent to help break down new oil in much shorter time than if transformer were entirely free of sludge.

33. *Oklahoma Gas and Electric Co.*—The date of manufacture has little to do with sludging except to define the quality of oil used at time in particular manufacturer's apparatus. No great improvement in sludging characteristics in low pour point oils over high pour point oils. The source of crude and degree of refining seem to govern this characteristic almost exclusively.

Sludge is a by-product of oxidation which is accelerated by heat, contact with oxygen and contact with metals (copper being a very good catalyst or oxidizing agent). Types of construction which reduce contact with oxygen (or air) reduce sludging. Per cent load, as a source of heat, influences the rate of sludging.

In an open-type free-breathing transformer, a constant top oil temperature of 85 C. will normally show an increase in neutralization number of 0.1 per month. At 60 C. the increase will be about 0.1 per yr. and at 50 C. about 0.05 per yr.

In our part of the country which has average annual ambient temperature of 15 C. and an average annual maximum of 40 C., we follow loading practice which seldom gives maximum oil temperature in excess of 70 C. This results in average life of 15 to 20 yr. for our insulating oil, without undue sludging except in rare instances.

We prefer to judge quality of oil by visual inspection of sludge deposited, verifying observation that oil has reached or is approaching "run-away" sludge value by neutralization number, color, power factor test, then either discard or re-refine it.

We experience some trouble with corrosion in open-type transformers and therefore add vents to many of our transformer tanks. Our spares are protected with breathers and large power units are of conservator construction.

35. *The Ohio Power Co.*—One bank of three 3750 kva water-cooled, single-phase transformers has given considerable trouble since installation in 1916. Design such that exciting current exceptionally high causing excess heating, and heavy sludge. Average load lately has been 80 to 90 per cent. Transformers have conservators. Excessive sludging eliminated by changing oil and renewing core bolt and clamping insulation.

41. *Utah Power and Light Co.*—Almost no trouble is experienced with sludging in transformers manufactured in the last 15 yr. Our experience, while not conclusive, leads us to believe that sludging of the older oils was largely due to manufacturing of that particular batch of oil rather than to load carried. One of the worst cases of sludging we ever experienced occurred in a bank of outdoor transformers carrying less than three-quarter load with cases sealed except for 2-in. vent pipes carried into the generating station.

This company has a number of transformers from predecessor companies that are more than 40 yr. old in which the original oil is still in use. Humidity in this area is 40 per cent or less during most of the year which may account for small amount of trouble with oil. Dielectric tests regularly made and oil filtered when not up to standard.

45. *Long Island Lighting Co.*—Sludging becoming serious as oil and equipment is becoming older. Transformers and regulators generally consist of two types: Open-breather and conservator (self-cooling). Date of manufacture 1914 to 1943. Loads run as high as 110 per cent full-load. Oil indicating excessive sludging is replaced with new oil.

46. *Consolidated Gas Electric Light and Power Co. of Baltimore.*—The greater part of oil in our power transformers is nitrogen protected. Oil so protected free from sludge troubles. The smaller modern power transformers without nitrogen protection have shown a greater rate of deterioration than those with nitrogen.

49. *Boston Edison Co.*—In transformers of one make manufactured between 1916 and 1926, the paraffin-base oil sludged badly, resulting in plugged radiators and an accumulation of sludge on core and windings; also verdigris deposits on bare copper, brass, and bronze parts inside transformer case.

50. *Detroit Edison Co.*—Sludging not serious since special care exercised in operating oil-filled equipment well below full-load capacity, thus comparatively low oil temperature, and rigorous inspection of both new and used oil in an effort to prevent even incipient sludge conditions. A need exists for an oil that will withstand high-temperature operation for long periods of time without sludging in order to utilize the full-load capacity of oil-filled electrical equipment.

63. *Potomac Electric Power Co.*—Considerable oxidation and clogging of coil ducts in non-conservator type of transformers carrying full load. No correction done except to lighten load and filter oil. With some 13-kv. transformers we found considerable deposits of oil sludge on the terminal board and windings. Dielectric strength of oil low due to poor breathing, allowing condensation on underside of cover. Additional breathers installed.

66. *Carolina Power and Light Co.*—Sludging generally increases with age of transformer, but some sludge much worse than others, probably due to insulation ingredients and circulating vents being more susceptible to stoppage. Sludging increases with temperature, whether heated by load, over-excitation, poor oil circulation, or otherwise. Some transformers carry heavy overloads without excessive sludging, while others get "hot" and sludge carrying only a part of their rated load. To combat sludge we filter oil and clean out transformers periodically. We have replaced some old oil with new oil supposed to contain "inhibitors" but the results have not yet been ascertained.

Respectfully submitted on behalf of Subcommittee IV,

L. B. SCHOFIELD.

REPORT OF SECTIONAL COMMITTEE C59

ON

ELECTRICAL INSULATING MATERIALS

Sectional Committee C59 on Electrical Insulating Materials held one meeting during the year on March 14, 1945, in Atlantic City, N. J.

In line with action taken at that meeting, confirmed by subsequent letter ballot vote, the American Standards Association was advised under date of September 20, 1945, that the following standards which are under the jurisdiction of Sectional Committee C59 so far as their ASA status is concerned and which have stood four years or more without revision have been reaffirmed by the sectional committee:

A.S.T.M. Standard Specifications for:

Rubber Matting for Use Around Electrical Apparatus or Circuits not Exceeding 3000 Volts to Ground (A.S.T.M. D 178 - 24; ASA C59.4—1935),

Rubber Insulating Tape (A.S.T.M. D 119 - 38; ASA C59.6—1939), and

A.S.T.M. Standard Methods of:

Testing Molding Powders Used in Manufacturing Molded Electrical Insulators (A.S. T.M. D 392 - 38; ASA C59.10—1941).

As a matter of record, the ASA was also advised of the publication in 1944 and 1945, of tentative revisions applying to the following A.S.T.M. standards which have been approved as American Standard on the recommendation of Sectional Committee C59:

A.S.T.M. Standard Methods of Testing:

Sheet and Plate Materials Used in Electrical Insulation (A.S.T.M. D 229 - 43; ASA C59.13—1944),

Laminated Tubes Used in Electrical Insulation (A.S.T.M. D 348 - 42; ASA C59.14—1943),

Laminated Round Rods Used in Electrical Insulation (A.S.T.M. D 349 - 42; ASA C59.15—1943), and

Electrical Insulating Oils (A.S.T.M. D 117 - 43; ASA C59.2—1944).

On September 20, 1945, the sectional committee recommended to the ASA that the NEMA Vulcanized Fibre Standards be approved as American Standard and that the A.S.T.M. Methods of Testing Shellac Used for Electrical Insulation (D 411 - 44) be reapproved as American Standard in their revised form.

The proposal that the revised Tentative Methods of Testing Molded Materials Used for Electrical Insulation (D 48 - 45 T) be submitted to the ASA for reapproval in their revised form is now under consideration in a special reviewing committee consisting of Messrs. C. R. Troop and H. S. Vassar.

The A.S.T.M. Standard Methods of Test for Insulation Resistance of Electrical Insulating Materials (A.S.T.M. D 257 - 38; ASA C59.3—1939) were revised by the Society in June, 1945, but submittal of the revised methods to the ASA for approval as American Standard has been withheld pending the incorporation of further revisions.

It is planned to bring up to date the List of Available Standards in the Electrical Insulating Field which had been prepared as the first step in compiling a library of available standards for electrical insulating materials to be deposited in the office of the secretary. It is the intent to harmonize duplicate or conflicting specifications to a single standard developed as a national standard and to fill in any gaps.

Respectfully submitted on behalf of the sectional committee,

H. L. Curtis,
Chairman.

R. E. Hess,
Secretary.

REPORT OF COMMITTEE D-10

ON

SHIPPING CONTAINERS*

Since its previous report to the Society in 1941, Committee D-10 on Shipping Containers held two meetings in New York, N.Y., on June 26, 1944, and on March 22, 1945. Both meetings were well attended.

During the past year the committee has been reorganized and its personnel enlarged from 16 to 68 members classified as follows: 28 producers, 24 consumers, and 16 general interests.

A set of By-Laws governing the committee was adopted subject to letter ballot. The present officers of the committee were reelected for the ensuing term of two years and R. L. Beach was elected to the newly created office of Vice-Chairman. An Advisory Committee was approved to consist of the officers of the main committee, the chairmen of the subcommittees and two additional members. The two members selected were Nathan Tufts and R. A. Wilkins.

In the reorganization of the committee, six subcommittees were approved and chairmen appointed as indicated:

Subcommittee I on Definitions of Terms, Edward Dahill, chairman,
Subcommittee II on Methods of Testing, E. R. Stivers, chairman,
Subcommittee III on Moisture and Water Vapor Resistance, R. W. Lahey, chairman,
Subcommittee IV on Performance Standards, R. F. Weber, chairman,
Subcommittee V on Correlation of Tests and Test Results, L. J. Markwardt, chairman, and
Subcommittee VI on Interior Packing, W. B. Lincoln, Jr., chairman.

Subcommittee I is compiling a dictionary of terms as a basis for work.

Subcommittee II has in preparation a compression test and a drop test for shipping containers which, in part, are based upon the present Tentative Method of Compression Test for Shipping Containers (A.S.T.M. Designation: D 642 - 45 T) and the Tentative Method of Drop Test for Shipping Containers (A.S.T.M. Designation: D 775 - 45 T) which methods are under the jurisdiction of Committee D-6 on Paper and Paper Products. When the revised methods are completed, these tests are to be placed under the jurisdiction of Committee D-10. It is expected that these two methods will be ready for submission as tentative later in the year. Subcommittee II is also giving consideration to a drum test for shipping containers. It is preparing a method on the inclined impact tester and vibration table.

Subcommittee III is working on standardized tests for water and moisture vapor resistance of shipping containers.

Respectfully submitted on behalf of the committee,

EDWARD DAHILL,
Chairman.

E. R. STIVERS,
Secretary.

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* Presented at the Forty-Eighth Annual Meeting of the Society, June 27, 1945.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-10 presented to the Society through the Administrative Committee on Standards the following:

New Tentative:

Compression Test on Shipping Containers (D 642 - 45 T) to supersede Standard Method D 642 - 43, and
Drop Test of Shipping Containers (D 775 - 45 T) to supersede Tentative Method D 775 - 44 T.

These recommendations were accepted by the Standards Committee on August 27, 1945, and the tentative methods appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

REPORT OF COMMITTEE D-11
ON
RUBBER AND RUBBER-LIKE MATERIALS*

Committee D-11 on Rubber and Rubber-Like Materials has not met since the 1944 Annual Meeting but several subcommittees have held meetings and the work of the committee has been advanced so far as possible by correspondence.

Committee D-11 wishes to record its sorrow and deep sense of loss in the death during the year of two of its very active subcommittee chairmen, Walter H. Juve and Louis P. Gould. Mr. Juve was a member of the Advisory Committee and chairman of Subcommittee XXIII on Hard Rubber in which capacity he had served since the organization of the subcommittee in 1938. O. M. Hayden has been designated to replace Mr. Juve on the Advisory Committee and H. J. Flikkie has been appointed chairman of Subcommittee XXIII.

Mr. Gould had served as chairman of Subcommittee XXII on Cellular Rubber since its formation in 1938. He has been succeeded by H. G. Bimmerman.

Recommendations Accepted by Committee E-10 on Standards

Subsequent to the 1944 Annual Meeting, Committee D-11 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Specifications for:

GR-S (Synthetic Rubber) Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is Not Required (D 812 - 44 T),

New Tentative Methods of Test for:

Resistance of Vulcanized Rubber or Synthetic Elastomers to Crack Growth (D 813 - 44 T),

Hydrogen Permeability of Rubber-Coated Fabrics (D 815 - 44 T),

Permeability of Vulcanized Rubber or Synthetic Elastomers to Volatile Liquids (D 814 - 44 T), and

Rubber Adhesives (D 816 - 44 T),

Tentative Revision of the Standard Method of:

Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (D 573 - 42),

Revised Tentative Specifications for:

Cellular Rubber Products (D 798 - 44 T),

Revised Tentative Methods of:

Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 - 44 T),

Testing Hard Rubber Products (D 530 - 44 T),

Testing Automotive Hydraulic Brake Hose (D 571 - 44 T),

Testing Cellular Rubber Products (D 552 - 44 T), and

Test for Indentation of Rubber by Means of the Durometer (D 676 - 44 T).

These recommendations were accepted[1] by Committee E-10 on December 13, 1944, and the new and revised tentatives and the tentative revision appear in the 1944 Book of A.S.T.M. Standards, Part III.

*** Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.**

[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-11 reported the following results of the letter ballot vote of a total of 91 ballots returned from a membership of 148: **D 812,** affirmative 34, negative 1, ballots marked "not voting" 56; **D 813,** affirmative 54, negative 0, ballots marked "not voting" 37; **D 815,** affirmative 33, negative 0, ballots marked "not voting" 58; **D 814,** affirmative 46, negative 0, ballots marked "not voting" 45; **D 816,** affirmative 41, negative 1, ballots marked "not voting" 49; **D 573,** affirmative 69, negative 0, ballots marked "not voting" 22; **D 798,** affirmative 38, negative 0, ballots marked "not voting" 53; **D 471,** affirmative 55, negative 0, ballots marked "not voting" 36; **D 530,** affirmative 35, negative 2, ballots marked "not voting" 54; **D 571,** affirmative 30, negative 0, ballots marked "not voting" 61; **D 552,** affirmative 41, negative 0, ballots marked "not voting" 50; **D 676,** affirmative 59, negative 2, ballots marked "not voting" 30.

The new Tentative Specifications for GR-S Sheath Compound for Electrical Cords provide a grade having somewhat lower tensile strength than that covered by the Emergency Specifications for GR-S Synthetic Rubber Sheath Compound for Electrical Insulated Cords and Cables (ES - 6a).[2] The committee found that a real need exists for the new grade for use in the very numerous applications which involve less severe mechanical wear than the emergency grade is designed to withstand and in which use of the latter would cause unnecessary hardship and expense.

The new Tentative Method D 813 is somewhat similar to, and employs the same flexing machine as, Method B of the Standard Methods of Dynamic Testing for Ply Separation and Cracking of Rubber Products (D 430 - 40) when the latter is used to test the resistance of rubber to cracking when flexed by repeated bending. The new method, however, measures the rate of crack growth instead of the resistance to initial cracking and is of particular importance in the evaluation of some of the new synthetic materials which differ from natural rubber in that they are much more resistant to initiation of cracking but fail more rapidly after a crack is started by a small bruise or cut.

The method for hydrogen permeability of coated fabrics (D 815) provides a test which is widely used for the evaluation of coated fabrics used in manufacturing inflatable goods such as balloons, pontons, and the like.

Method D 814 has also been widely used and had not previously been generally available in standardized form. It is particularly valuable for comparing the behavior of different rubbers and synthetics when used in contact with such liquids as gasoline, aromatic fuels, and the like.

The methods for testing adhesives (D 816) meet a need which has long been recognized and which became acute with the advent of the war. The work in the committee on the development of these cement methods was urgently requested by representatives of various branches of the Armed Forces and by industry. Standardization work in the field of rubber cements is difficult because of the unique characteristics of these materials and the many variables which exist. The committee believes, however, that a good start has been made in the new tentative methods but recognizes that experience with these may indicate need for extensive revisions and additions.

The tentative revision of the standard method for oven aging (D 573) involves a change in the note covering the use in certain cases of temperatures higher than the original standard of 70 C. The note already provided for 90 C. when testing natural rubber compounds intended for use at elevated temperatures, but even this increase has been found insufficient in the case of the new synthetic rubbers which are protected with antioxidants and which age so slowly at the lower temperatures as to make the test impractical for evaluating their utility in any type of service. In the extensive experimental work which has been done during the development of synthetic rubbers, most of the aging tests have been carried out at 100 C. for normal service and much higher for service at elevated temperatures. The new revision covers the use of the 100 C. temperature.

The revision of specifications for cellular rubbers (D 798) increases the permissible deflection change at low temperature for the SC compounds and corrects what is believed to have been an error as the original values prevent use of certain synthetic materials in the compounds which are well suited to the purpose and which were intended to be allowed.

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[2] 1944 Book of A.S.T.M. Standards, Part III.

The revisions in Tentative Methods D 471 amplify the instructions concerning test fluids and add standard reference fuels for gasoline immersion tests as discussed in the 1944 Annual Report.

The changes in the hard rubber methods (D 530) alter the requirements for preparation of test specimens and improve the procedure for conducting the Rockwell Hardness test on this material. In the revised methods for testing automotive hydraulic brake hose (D 571) a cold test has been added for evaluation of the suitability of this product for use under low-temperature conditions. The changes in the methods of testing cellular rubbers restrict the thickness of the standard test slabs to $\frac{1}{2}$ in. as other thicknesses have been found unnecessary. The revision of the Durometer hardness test (D 676) amplifies the scope defining the applicability of the method and also adds a section on temperature of test establishing normal temperature limits and providing for use of the instrument in low-temperature testing. In addition, the normal time of reading was changed to be immediately after application of the instrument with provision for use of readings 15 sec. after application for special purposes when so indicated.

EMERGENCY ALTERNATE PROVISIONS AND EMERGENCY SPECIFICATIONS

No new emergency specifications were recommended during the year but Emergency Alternate Provisions EA - D 470, EA - D 754, and EA - D 755 were accepted by Committee E-10 on November 13, 1944, whereby a new emergency flame test was issued in connection with the Standard Methods of Testing Rubber Insulated Wire and Cable (D 470 - 41). A flame test was issued in connection with the standard methods and corresponding requirements of certain specifications. The new horizontal flame test has been established on an emergency basis by the Underwriters' Laboratories and its use in place of the former method is necessary in order to comply with the Underwriters' requirements during the emergency.

At the same time, a revision was accepted in the emergency alternate provisions applying to the Standard Specifications for Insulated Wire and Cable: Ozone-Resistant Type Insulation (EA - D 574a) whereby the minimum requirement for elongation at rupture after aging by the air oven and oxygen pressure methods is reduced slightly because experience has indicated that the previous requirement cannot be consistently met. The new and revised emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part III.

Revised emergency alternate provisions applying to the Standard Specifications for Friction Tape (D 69 - 38) were accepted by Committee E-10 on January 31, 1945. These revisions provide for a better quality of tape than was required by the previous provisions and also specify different types of packaging. The improved quality is now justified because of new techniques based on experience since the war emergency. The previous war quality of tape has in many cases not been satisfactory to the consumer. The reason for the change in packaging is obvious in that war shortages necessitate different types of wrapping than originally specified. These revised emergency alternate provisions EA - D 69b have been issued with the 1944 Book of A.S.T.M. Standards, Part III.

I. NEW TENTATIVES

Tentative Methods of Identification and Quantitative Analysis of Synthetic Elastomers.[3]—These methods of analysis of synthetic elastomers give a qualitative procedure with confirmatory tests whereby the synthetic rubber used in compounds may be identified together with quantitative methods applicable for estimation of the different polymers, in so far as this is now possible. A section is also included covering quantitative determination of certain of the more important compounding ingredients. These methods are based on published reports from a number of laboratories and on laboratory trials by members of the section of Subcommittee XI on Chemical Analysis, which is responsible for the recommendation. The methods are very urgently needed for use with the new synthetic materials concerning the analysis of which very limited information has been generally available. It is anticipated that the methods will require amplification and revision as more knowledge in this new field is developed but it is felt that early presentation on a tentative basis of these recommendations, which are considered to be the best now known, will be of great value.

Tentative Recommended Practice for Conditioning of Rubber and Plastic Materials for Low-Temperature Testing.[3]—The need for a general presentation on the cold conditioning of specimens of rubber and rubber-like materials prior to application of any specific low-temperature test was discussed in the 1944 Annual Report.[4] This recommendation covers the general theory underlying all low-temperature testing, the characteristic behavior of natural rubber, synthetic rubber, rubber-like materials, and plastics, and the conditioning procedures necessary in making low-temperature tests. It has been developed by a joint section of Subcommittee XXV on Low-Temperature Tests with representatives of Committee D-20 on Plastics. It is believed the recommendation will be very useful in supplementing the present procedures for low-temperature testing of these materials.

Tentative Specifications for Natural Rubber Cups for Use in Hydraulic Actuating Cylinders.[3]—These specifications were prepared by Section IX of Technical Committee A on Automotive Rubber in response to an urgent request from the U. S. Army Ordnance Department and the automotive manufacturers. Use of natural rubber in making this highly specialized product has been allowed in a number of critical applications long after it was necessary to use synthetics for most other products. Development of synthetic rubber cups has been in progress and it is expected that specifications for them will soon be completed. Meanwhile, there is still need for the natural rubber cup specifications and this probably will continue. These specifications include a number of tests of the performance type. Because of the importance of this product in a number of critical uses and in applications involving safety hazards, Technical Committee A has requested approval and publication both by the Society of Automotive Engineers and A.S.T.M.

II. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD

The committee recommends the adoption as standard of the tentative revision[2] of the Standard Method of Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (D 573 – 42). This revision which was approved by Committee E-10 last year provides for the use of 100 C. temperature in testing synthetic rubbers, and is in general use.

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[3] These methods and specifications were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 467 (1944).

III. TENTATIVE SPECIFICATIONS AND METHODS CONTINUED AS TENTATIVE WITHOUT REVISION

The committee recommends that all the tentative specifications and methods of test under its jurisdiction be continued as tentative without revision. Many of these are actively under consideration for revision which has not been completed because of the necessary omission of meetings. In all other cases, adoption as standard at the present time is considered inadvisable because of war conditions.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 148 voting members; 93 members returned their ballots with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVES			
Methods for Identification and Quantitative Analysis of Synthetic Elastomers	68	0	25
Rec. Practice for Conditioning of Rubber and Plastic Materials for Low-Temperature Testing	66	1	26
Spec. for Natural Rubber Cups for Use in Hydraulic Actuating Cylinders	31	0	62
II. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD			
Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (D 573 - 42)	73	0	20

ACTIVITIES OF SUBCOMMITTEES

Many of the subcommittees of Committee D-11 have important work in progress but only those activities which it is believed will soon result in recommendations being presented to the Society are covered in this report.

Technical Committee A on Automotive Rubber (W. J. McCortney, chairman).—During the past year, Technical Committee A has met regularly at bimonthly intervals and has carried on extensive standardization activities in the automotive and aeronautical fields. Through its various sections, work is in progress on the investigation and development of standardized test methods for use on motor mountings, bumpers, gaskets, oil seals, and V-belts. Specifications for automotive windshield wiper hose have been completed and referred to the Society of Automotive Engineers for publication. In addition, specifications for coolant system hose and for fuel and oil line hose are practically completed and will be recommended to the S.A.E. for publication as tentative in the near future. These specifications cover the products as made from synthetic rubber. Also, specifications for hydraulic brake cups made using synthetic rubber are expected to be available soon supplementing those for natural rubber cups[3] being recommended for publication as tentative at this time.

The committee expects soon to recommend revisions in the Tentative Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735 - 43 T) covering inclusion of new RP compound tables which deal with material made from rubber-like plastics, the addition of values now omitted in the RS tables for A.S.T.M. hardness and the 20 per cent deflection test, changes in the compression set limits now given in the SC tables which have been found too low in some cases for commercial production, and other revisions which may seem desirable.

As a result of work on oven aging, a new method for high-temperature air aging in test tubes heated in an oil bath has been developed and has been found to be especially useful for work with synthetic materials. Experimental data have already been published in the ASTM Bulletin[5] and it is expected that a tentative method based on these studies will be recommended this summer. All of the above recommendations suitable for general industrial use will be presented to the Society through Committee E-10. In addition to the activities already mentioned, Technical Committee A is cooperating very closely with the Ordnance Departments of the Army and the Navy and is proving to be a very valuable technical standardization contact between suppliers and the Armed Forces.

Subcommittee V on Insulated Wire and Cable (R. A. Schatzel, chairman).—This subcommittee expects soon to recommend publication as tentative[6] of the Emergency Specifications for GR-S Synthetic Rubber Sheath Compound for Electrical Insulated Cords and Cables (ES - 6a) after adding requirements covering the minimum permissible elongation of the compound after aging. These specifications are needed for severe service applications where the GR-S sheath compound (D 812) already discussed in this report would not be satisfactory. In addition, it is probable that the subcommittee will recommend withdrawal of the emergency alternate provisions applicable to several of the specifications for which it is responsible.

Subcommittee IX on Insulating Tape. (W. H. S. Youry, chairman).—This subcommittee has completed revisions in the Standard Specifications for Rubber Insulating Tape (D 119 - 38)[2] which will probably be presented to the Society soon through Committee E-10 as a revision of the emergency alternate provisions applicable to these specifications. Both friction tape and rubber insulating tape are still definitely on an emergency basis because of the unavailability of natural rubber. Developments of synthetics and reclaims and improved techniques in their use are making possible the production of somewhat better tapes than the first emergency grades which were not very satisfactory but which helped greatly in meeting the war crisis.

Subcommittee XIX on Tests for Properties of Rubber and Rubber-Like Materials in Liquids (J. A. Baty, chairman).—This subcommittee has found that the original specification limits for the standard petroleum-base oils for immersion tests given in Table I of the Tentative Methods of Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 - 44 T) are too wide to assure good reproducibility of results when oils from different sources are used with the same rubbers in different laboratories. Also, in some cases, the differences in swelling action of the oils from different sources on different rubbers of similar characteristics were greater than the differences between the rubbers. The subcommittee therefore expects to recommend closer tolerances for the oils and in order to meet these, it will be necessary to establish standard lots of oil from the same source for use by all laboratories. This is now being arranged and proposed revisions in Methods D 471 will be presented to the Society through Committee E-10.[6] The subcommittee is continuing its research on the action of different oils and fuels on rubber and synthetic materials.

Subcommittee XXII on Cellular Rubber (H. G. Bimmerman, chairman).—This subcommittee is giving consideration to revisions in the Tentative Specifications for Cellular Rubber Products (D 798 - 44 T). It now appears that the values for Suffix B, compression set of the sponge rubbers in Table IV covering the SC oil-resisting class are too low to be met consistently in normal production when certain of the most important synthetics are employed. Also, the values in pounds per square inch for indentation, 25 per cent deflection, of uncored latex foam rubbers have tolerances so wide as to cause difficulty in classifying the different grades. In addition, the dimension tolerances given for information only in Table V for uncored foamed latex rubber are closer than necessary for many important automotive uses causing excessive rejections and expense. When agreement is reached on desirable changes, it is expected that the subcommittee will present its recommendations to the Society through Committee E-10.[6]

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[5] G. D. McCarthy, A. E. Juve, H. Boxser, M. Sanger, S. R. Doner, E. N. Cunningham, J. F. McWhorter, and R. H. Crossley, "High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds," ASTM Bulletin, No. 132, January, 1945, p. 33.

[6] See Editorial Note, p. 318.

This report has been submitted to letter ballot of the committee which consists of 148 members; 93 members returned their ballots, of whom 83 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

SIMON COLLIER,
Chairman.

ARTHUR W. CARPENTER,
Secretary.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 9, three proposed tentatives referred to in the report were submitted by Committee D-11 and accepted by the Administrative Committee on Standards on June 27, 1945. The new tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

Subsequent to the Annual Meeting, Committee D-11 presented to the Administrative Committee on Standards the following recommendations:

Revised Tentative Specifications for:

Cellular Rubber Products (D 798 - 44 T)
Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 - 43 T), and
Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 - 44 T).

Revised Tentative Method for:

Testing Cellular Rubber Products (D 552 - 44 T).

Withdrawal of Emergency Alternate Provisions:

EA - D 523a applying to the Tentative Specifications for Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 523 - 44 T),
EA - D 469a applying to the Standard Specifications for Insulated Wire and Cable: Heat-Resisting Rubber Compound (D 469 - 41), and
EA - D 353 applying to the Standard Specifications for Insulated Wire and Cable: Preformed Rubber Compound (D 353 - 41).

Tentative Specifications for:

GR-S Synthetic Rubber Sheath Compound for Electrical Insulated Cords and Cables (D 866 - 46 T), formerly Emergency Specifications ES - 6a, revised.

Tentative Revision of Specifications for:

Insulated Wire and Cable: Heat-Resisting Rubber Compound (D 469 - 41).

These recommendations were accepted by the Standards Committee on January 10, 1946. The revised tentatives, the tentative revisions, and the new tentative appear in the compilation "A.S.T.M. Standards on Rubber and Rubber-Like Materials," February, 1946.

REPORT OF COMMITTEE D-12

ON

SOAPS AND OTHER DETERGENTS*

Committee D-12 on Soaps and Other Detergents held no meetings during the past year. Due to Office of Defense Transportation restrictions and the difficulties of travel, the meeting which had been scheduled for February 19 and 20, 1945, in New York, N. Y., was canceled.

The most outstanding happening in the affairs of the committee was the loss of its chairman, Harry P. Trevithick, through death on January 17, 1945. His place will be difficult to fill both in the committee and in the hearts of our members.

RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS

Subsequent to the 1944 Annual Meeting, Committee D-12 recommended to Committee E-10 on Standards that the Emergency Alternate Provision in the Standard Specifications for Built Soap, Powdered (EA – D 533) be withdrawn. This recommendation was accepted[1] by Committee E-10 on August 28, 1944.

On May 4, 1945, Committee E-10, on the recommendation of Committee D-12, accepted a new Tentative Method of Chemical Analysis of Soaps Containing Synthetic Detergents (D 820 – 45 T)[2] and the proposed Tentative Revision[3] of the Standard Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 – 44), together with several revisions and additions to the Tentative Definitions of Terms Relating to Soaps and Other Detergents (D 459 – 44 T) as given in the report of Subcommittee III on Nomenclature and Definitions.

At its meeting on March 13, 1944, the Advisory Committee directed the secretary to send a questionnaire to the members of Committee D-12 to ascertain their interest in the work of the various subcommittee sections, their willingness to carry on the cooperative work of the sections in whose activities they are interested, and what facilities they have for doing this work, as for example, instruments such as washing machines, colorimeters, reflectometers, photometers, sudsing apparatus, etc., that may be available in the laboratories of the members.

It is regretted that a better response was not received from the members with respect to this questionnaire. Many members gave answers which were too superficial to decide the question at hand.

After spending a number of hours in endeavoring to analyze the replies, the secretary has arrived at the conclusion that the entire effort was practically fruitless. In the near future a more detailed questionnaire will be prepared in an effort to secure more definite information. It is hoped that the response to this questionnaire will be more adequate than it was to the previous one.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-12 reported the following results of the letter ballot vote from a committee membership of 87: D 820 and D 459, affirmative 55, negative 0, ballots marked "not voting" 12; D 460, affirmative 53, negative 0, ballots marked "not voting" 14.

[2] This method was accepted as tentative by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[3] See p. 322.

RECOMMENDATIONS AFFECTING STANDARDS

As referred to in the subcommittee reports, the committee is recommending the adoption as standard of two tentative specifications and two tentative methods of test and the continuation of a tentative revision for another year. The standard and tentatives affected are listed in Table I.

The recommendations in this report have been submitted to letter ballot of the committee which consists of 87 members, with the results shown in Table I.

EMERGENCY ALTERNATE PROVISIONS

No changes are recommended by the committee at this time in the following Emergency Alternate Provisions under its jurisdiction, since the conditions which made them necessary have not improved:

Designation	*Emergency Alternate Provisions in:*
EA - D 455	Standard Specifications for Milled Toilet Soap (D 455 - 39),
EA - D 496a	Standard Specifications for Chip Soap (D 496 - 39),
EA - D 498a	Standard Specifications for Powdered Soap (Nonalkaline Soap Powder) (D 498 - 39),
EA - D 499	Standard Specifications for White Floating Toilet Soap (D 499 - 39),
EA - D 535	Standard Specifications for Palm Oil Solid Soap (Type A, Straight; Type B, Blended) (D 535 - 41),
EA - D 536	Standard Specifications for Palm Oil Chip Soap (Type A, Straight; Type B, Blended) (D 536 - 42),
EA - D 592	Standard Specifications for Olive Oil Solid Soap (Type A, Straight; Type B, Blended) (D 592 - 42),
EA - D 593	Standard Specifications for Salt-Water Soap (D 593 - 42), and
EA - D 630	Standard Specifications for Olive Oil Chip Soap (Type A, Straight; Type B, Blended) (D 630 - 42).

This recommendation has been approved by letter ballot vote of Subcommittee II on Specifications and will be referred to Committee E-10 on Standards.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Testing (J. B. Crowe, chairman):

Section A on Soaps (M. L. Sheely, chairman) developed the Tentative Method of Chemical Analysis of Soaps Containing Synthetic Detergents (D 820 - 45 T)[2] and the tentative revision of the Standard Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 - 44)[3] which, as mentioned earlier in this report, were recently accepted by Committee E-10.

Section B on Sulfonated Detergents (Ralph Hart, chairman) proposed that the Tentative Methods of Test for Water-Immiscible Organic Solvents Volatile with Steam in Sulfonated and Sulfated Oils (D 500 - 43 T) be adopted as standard, as recommended earlier in this report.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. ADOPTION OF TENTATIVES AS STANDARD			
Spec. for Tetrasodium Pyrophosphate (Anhydrous) (D 595 - 44 T)	62	0	6
Spec. for Liquid Toilet Soap (D 799 - 44 T)	56	0	12
Test for Water-Immiscible Organic Solvents Volatile with Steam in Sulfonated and Sulfated Oils (D 500 - 43 T)	59	0	9
Chemical Analysis of Industrial Metal Cleaning Compositions (D 800 - 44 T)	59	0	9
II. CONTINUATION OF TENTATIVE REVISION OF STANDARD			
Methods of Sampling and Chemical Analysis of Special Detergents (D 501 - 43)	58	0	10

Section C of Subcommittee I and Section D of Subcommittee II, on Dry Cleaning Detergents (Mary Deck Hale, chairman) have been inactive due to the extended illness of Dr. Hale. George P. Fulton of the National Association of Dyers and Cleaners, former chairman of these sections, has been discharged from the U. S. Navy and will relieve Dr. Hale of work on these sections.

Section D on Special Detergents (W. H. Koch, chairman) has had no problems assigned to it during the year. The section recommended that the tentative revision of the Standard Methods of Sampling and Chemical Analysis of Special Detergents (D 501 - 43) be continued as tentative for another year.

Subcommittee II on Specifications (F. W. Smither, chairman):

Section A on Soap Specifications (Frederick Krassner, chairman) recommends that the present Emergency Alternate Provisions remain in force for another year as mentioned earlier in this report.

This section also recommended that the Tentative Specifications for Liquid Toilet Soap (D 799 - 44 T) be adopted as standard since no adverse criticisms have been received during the year.

Section G on Metal Cleaners (J. C. Harris, chairman) recommended that the Tentative Methods of Chemical Analysis of Industrial Metal Cleaning Compositions (D 800 - 44 T) be adopted as standard.

Subcommittee III on Nomenclature and Definitions (C. A. Marlies, chairman):

Following review of the Tentative Definitions of Terms Relating to Soaps and Other Detergents (D 459 - 44 T),[4] the subcommittee recommended the following revisions and additions to the tentative definitions which, as indicated earlier in this report, have been approved by Committee E-10 on Standards:

Change the note following the definition of "surface active agent," from its present form: namely,

NOTE.—Surface Active Agent is the general term which includes soluble detergents used in liquid medium, wetting agents, and foaming agents.

to read as follows:

NOTE.—Surface Active Agent is the general term which includes soluble detergents in liquid medium, dispersing agents, emulsifying agents, foaming agents, penetrating agents, and wetting agents.

Add to the definition for "titer" the phrase "by a standardized procedure."

Change the definition of "wetting agent" to read as follows by the omission of the words in brackets:

Wetting Agent.—A composition which when added to a liquid medium increases the spreading of the medium on a surface [or the penetration of the medium into a material].

Add the following new definitions:

Nonionic Detergent.—A detergent which produces electrically neutral colloidal particles in solution.

Penetrating Agent.—A composition which when added to a liquid medium increases the penetration of the medium into a porous material.

Subcommittee IV on Papers and Publications (W. H. Koch, chairman):

A paper by J. C. Harris on "Corrosion Testing of Water-Soluble Aluminum Cleaners" appeared in the August, 1944, issue of the ASTM BULLETIN.

The subcommittee still has under consideration the paper by W. G. Morse on "Cleaning and Cleaning Materials."

This report has been submitted to letter ballot of the committee which consists of 87 members; 67 members returned their ballots, of whom 66 have voted affirmatively, and 1 negatively.

Respectfully submitted on behalf of the committee,

F. W. SMITHER,
Vice-Chairman.

B. S. VAN ZILE,
Secretary.

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[4] 1944 Book of A.S.T.M. Standards, Part III.

APPENDIX

TENTATIVE REVISION[1] OF STANDARD METHODS OF SAMPLING AND CHEMICAL ANALYSIS OF SOAPS AND SOAP PRODUCTS (D 460 – 44)[2]

New Sections.—Add the following as new sections 68 and 69 on the determination of free alkali and potassium carbonate in potash paste soaps:

FREE ALKALI AND POTASSIUM CARBONATE IN POTASH PASTE SOAPS

68. *Reagents.*—(*a*) *Standard Sulfuric Acid (0.5 N).*

(*b*) *Methyl Orange Indicator.*—Prepare a 0.1 per cent solution in distilled water.

(*c*) *Phenolphthalein Indicator.*—Prepare a 1 per cent solution in neutral ethyl alcohol (95 per cent) (see Section 53(*a*)).

(*d*) *Standard Sodium Hydroxide Solution (0.5 N).*

(*e*) *Neutral Ethyl Alcohol (Absolute).*—Freshly boiled absolute ethyl alcohol neutral to phenolphthalein; either Formula No. 3A or No. 30 of the U.S. Bureau of Internal Revenue.

69. *Procedure.*—(*a*) Weigh 10 ± 0.01 g. of the sample into a 250-ml. beaker and dissolve in 100 ml. of freshly boiled distilled water. Add a measured amount of 0.5 N H_2SO_4 sufficient to make the solution acid to methyl orange indicator, and bring to incipient boiling until fatty acids separate out in a clear layer. Excessive boiling should be avoided to preclude the possibility of volatilization of any low molecular weight fatty acids that may be present.

(*b*) Add 0.5 ml. of phenolphthalein indicator, and while stirring the contents of the beaker, titrate with 0.5 N NaOH until the solution is almost neutral but still slightly on the acid side to phenolphthalein.

(*c*) Evaporate to dryness on a steam bath and dissolve in 200 ml. of neutral ethyl alcohol (absolute). Titrate with 0.5 N NaOH to neutrality to phenolphthalein.

(*d*) Determine CO_2 on a separate sample by the train-absorption method (Section 45) or the evolution-volumetric method (Section 48).

70. *Calculations.*—Calculate the percentages of K_2CO_3 and free KOH as follows:

$$K = C \times 3.140$$

$$K_2CO_3\text{, per cent} = \frac{K}{W_1} \times 100$$

$$V_k = \frac{K}{0.03455}$$

$$V_t = V_1 - (V_2 + V_3)$$

$$\text{Free KOH, per cent} = \frac{(V_t - V_k) \times 0.02805}{W_2} \times 100$$

where:

K = grams of K_2CO_3 equivalent to C,
C = grams of CO_2 (Section 69 (*d*)),
W_1 = grams of sample used for determination of CO_2 (Section 69 (*d*)),
V_k = milliliters of 0.5 N H_2SO_4 equivalent to K_2CO_3,
V_t = milliliters of 0.5 N H_2SO_4 equivalent to free KOH + K_2CO_3,
V_1 = milliliters of 0.5 N H_2SO_4 used to acidify sample (Section 69 (*a*)),
V_2 = milliliters of 0.5 N NaOH required for titration of aqueous solution (Section 69 (*b*)),
V_3 = milliliters of 0.5 N NaOH required for titration of alcoholic solution (Section 69 (*c*)), and
W_2 = grams of sample used for titration procedure (Section 69 (*a*)).

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[1] This tentative revision was accepted by Committee E-10 on Standards, May 4, 1945.

[2] 1944 Book of A.S.T.M. Standards, Part III, p. 944.

REPORT OF COMMITTEE D-13
ON
TEXTILE MATERIALS*

Committee D-13 on Textile Materials held only one meeting during the year, in New York, N. Y., on October 18 to 22, 1944. The usual spring meeting was canceled in order to conform to the rulings of the Office of Defense Transportation. Interest at the October meeting was excellent as evidenced by the registered attendance of 233 members and guests, and by the fact that 15 of the subcommittees and sections of Committee D-13 held well - attended meetings. The executive direction of the affairs of the committee required two meetings of the officers and one meeting of the Advisory Committee.

Through the medium of a questionnaire sent to all members, the committee is endeavoring to assess the effectiveness of its present type of organization and procedure with particular thought to post-war developments in the field of new textile fibers and to any demand for standards for ultimate consumer goods which may materialize. A special committee, under the chairmanship of R. H. Brown, is now reviewing the replies and will make recommendations.

Committee D-13 has taken cognizance of the proposal of the British Textile Institute to use the term "rayon" as a generic term for all man-made fibers. This is in marked disagreement with the definition adopted by Committee D-13 in 1926, which appears in the Standard Methods of Testing and Tolerances for Continuous Filament Rayon Yarns (D 258 - 44).[1] The A.S.T.M. definition restricted the term "rayon" to fibers derived from a cellulose base, and it has not been changed since it was first adopted. The same concept has also been promulgated by the Federal Trade Commission, the Federal Tariff Commission, and has always been so recognized throughout the textile industry in the United States. A. G. Scroggie, chairman of Subcommittee B-2 on Nomenclature and Definitions, who was delegated to act for Committee D-13, has presented to the British Textile Institute the objections of Committee D-13 to the British proposal, and has prepared a short paper comparing the divergent points of view. In order to inform the textile industry of the situation, this paper has been published in textile trade journals in the United States and has been submitted for publication in a similar manner in Great Britain. Consideration is being given to the possibility of securing an agreement between the two countries through the United Nations Standards Coordinating Committee.

Special mention should be made of the action of Committee D-13 in adopting a recommended practice for a universal yarn numbering system based on grex units. This method is sponsored by Subcommittee B-2. This system provides a direct and decimalized method, based on metric units, and is offered as a substitute for the various and widely differing methods now used in the several branches of the textile industry. It is hoped that the new method may eventually become a universal system and be used for all types of yarns and related products.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 Book of A.S.T.M. Standards, Part III.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. New Tentatives			
Recommended Practice for Yarn Numbering	102	7	37
Test for Evaluating Treated Textiles for Permanence of Resistance to Microorganisms	84	1	61
II. Revisions of Tentatives			
Def. of Terms Relating to Textile Materials (D 123 - 44 T).	119	3	24
Test for Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 - 41 T)	71	0	75
Test for Resistance of Textile Fabrics to Microorganisms (D 684 - 42 T)	76	1	69
Testing and Tolerances for Rope (D 738 - 43 T)	47	0	99
Testing and Tolerances for Spun, Twisted, or Braided Products Made from Flax, Hemp, Ramie, or Mixtures Thereof (D 739 - 43 T)	48	0	98
III. Revision of Standard, and Reversion to Tentative			
Test for Colorfastness of Colored Textiles to Light (D 506 - 41)	78	3	65
IV. Tentative Revision of Standards			
Testing Wool Felt (D 461 - 44)	50	2	94
Testing and Tolerances for Single Jute Yarn (D 541 - 41)	43	1	102
V. Adoption of Tentative as Standard			
Def. of Terms Relating to Textile Materials (D 123 - 44 T), comprising terms turn; yarn, cross-blended; and yarn, self-blended, as revised	136	0	26
VI. Adoption as Standard of Tentative Revisions of Standards			
Spec. for Textile Testing Machines (D 76 - 42; ASA L 15.1-1943)	112	2	38
Testing Wool Felt (D 461 - 44)	61	0	91

RECOMMENDATIONS AFFECTING STANDARDS

Committee D-13 is presenting for publication as tentative one new recommended practice, one new method of test, and is recommending the revision of five tentatives, the reversion to tentative and revision of one standard, tentative revisions of two standards, and the adoption as standard of one tentative and two tentative revisions of standards. The revisions being presented are included in detail in the Appendix and are accompanied, where necessary, by brief statements of the reasons for such revisions. The new tentative recommended practice, the new method of test, and the existing standards affected are listed in Table I and are also referred to under the subcommittee activities.

These recommendations have been submitted to letter ballot of the committee which consists of 299 members, the results being shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

The recommendations being submitted indicate that the various subcommittees and sections have been quite active during the year in spite of war-time restrictions. Many important projects are under consideration and are mentioned briefly in the following summary of subcommittee activities.

Subcommittee A-1 on Cotton and Its Products (K. B. Cook, chairman):

Section I on Cotton (M. E. Campbell, chairman) recommends that the Tentative General Methods of Testing Cotton Fibers (D 414 - 40 T) be continued as tentative pending further study of revisions for the improvement of the present methods and the addition of new methods for the measurement of length and strength of cotton fibers.

Section II on Cotton Yarns and Threads (W. R. Marsden, chairman) is studying the Standard General Methods of Testing and Tolerances for Cotton Yarns (D 180 - 44) with a view to improving them in some respects.

Section IV on Tire Fabrics (Martin

Castricum, chairman) recommends that the tentative revisions of the Standard Methods of Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 – 42) be continued as tentative for another year pending a complete revision of the standard to include methods of testing rayon tire cord. This revision is in process of development.

Subcommittee A-2 on Rayon and Its Products (A. M. Tenney, chairman):

Section I on Rayon (J. B. Goldberg, chairman) is studying Standard Methods of Testing and Tolerances for Continuous Filament Rayon Yarns (D 258 – 44) with respect to proposed revisions.

Subcommittee A-3 on Wool and Its Products (A. G. Ashcroft, chairman):

Section I on Wool (Werner von Bergen, chairman) recommends that the tentative revision of the Standard Specifications and Methods of Test for Fineness of Wool Tops (D 472 – 41) be continued as tentative for the reason that research work is still in progress and sufficient data has not been accumulated to warrant any action at this time.

This section is studying methods for the determination of vegetable matter content of wool and is continuing its interlaboratory studies of the sampling of fleeces and the various methods of measuring fineness.

Section II on Felt (G. H. Harnden, chairman) recommends the adoption as standard of the tentative revision[1] of the Standard Methods of Testing Wool Felt (D 461 – 44)[1] which covers the determination of acid in felt by the pyridine extraction method, and that the remainder of the tentative revision which provides certain definitions be continued as tentative.

As a tentative revision[2] of Standard Methods D 461 the section recommends new sections on sampling, a method for the determination of air resistance of filter felts, and an immersion test for water absorption of felt as given in the Appendix. The section also recommends as a tentative revision changes in the title of Standard Methods D 461, and the sections on scope and weight as set forth in the Appendix.

Section III on Woolen and Worsted Yarns (Fred Noechel, chairman) is conducting a study to establish a commercial moisture regain for hand knitting yarns.

Subcommittee A-4 on Asbestos and Its Textile Products (F. S. Mapes, chairman):

This subcommittee recommends that the Tentative Specifications for Woven Asbestos Cloth (D 677 – 42 T) be continued as tentative pending the completion of work now in progress on a revision of the table of properties.

The subcommittee is studying methods for determination of magnetic iron in asbestos fibers.

Subcommittee A-5 on Bast and Leaf Fibers and Their Products (S. J. Hayes, chairman):

This subcommittee recommends for publication[2] a revision, as given in the Appendix, of the ethylene dichloride extraction method in Standard Methods of Testing and Tolerances for Single Jute Yarn (D 541 – 41) and a similar revision in Tentative Methods of Testing and Tolerances for Rope (Leaf and Bast Fibers) (D 738 – 43 T) and for Spun, Twisted, or Braided Products Made from Flax, Hemp, Ramie, or Mixtures Thereof (D 739 – 43 T).

The subcommittee recommends that Tentative Methods of Testing and Tolerances for Jute Rove and Plied Yarn for Electrical and Packing Purposes (D 681 – 42 T) be continued as tentative pending a proposed revision.

Subcommittee A-6 on Household and Garment Fabrics (Ruth O'Brien, chairman):

This subcommittee recommends that the Tentative Specifications for Bleached

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[2] See Editorial Note, p. 328.

Wide Cotton Sheeting (D 503 - 40 T), for Bleached Cotton Broadcloth (D 504 - 41 T), for All Wool, All Cotton, and Wool and Cotton Blanketing (Household) (D 576 - 40 T), for Medium-Weight Cotton Corduroy Fabrics (D 625 - 41 T), and for Finished, All-Cotton, Upholstery Tapestries (D 678 - 42 T) be continued as tentative due to the inability to obtain representative peacetime fabrics for the necessary further study of the specifications for these fabrics.

Subcommittee A-8 on Glass Fiber and Its Products (Dean Harvey, chairman):

This subcommittee is studying methods of measuring length and twist of yarns, effect of jaws on tensile strength of yarn, and compatability of varnish and fiberglass yarn. A special committee is making a statistical study of sampling methods.

Subcommittee B-1 on Methods and Machines (W. D. Appel, chairman):

Section I on Methods (W. D. Appel, chairman) recommends that the Tentative Methods for Identification of Fibers in Textiles (D 276 - 43 T), of Quantitative Analysis of Textiles (D 629 - 42 T), for Colorfastness to Atmospheric Gases of Dyed Cellulose Acetate Rayon (D 682 - 42 T), and for Air Permeability of Textile Fabrics (D 737 - 43 T) be continued as tentative pending further revision.

This section also recommends that the Standard General Methods of Testing Woven Textile Fabrics (D 39 - 39) and the Tentative Methods of Quantitative Analysis of Textiles (D 629 - 42 T) be editorially revised as set forth in the Appendix.

Section II on Machines (H. J. Ball, chairman) recommends the adoption as standard[2] of the tentative revision in the Standard Specifications for Textile Testing Machines (D 76 - 42) which provides more definite specifications for the types of machines and their operations, and a general basis for verification of the testing machines for accuracy.

Subcommittee B-2 on Nomenclature and Definitions (A. G. Scroggie, chairman):

This subcommittee is recommending for publication a proposed Tentative Recommended Practice for a Universal System of Yarn Numbering.[3]

The subcommittee recommends the adoption as standard of the definitions of the terms "turn," "yarn, cross-blended," and "yarn, self-blended" appearing in the Tentative Definitions of Terms Relating to Textile Materials (D 123 - 44 T), revised as given in the Appendix.

The subcommittee recommends for publication, tentative definitions for breaking length, duck, nylon, textile nylon, wool, and yarn intermediates.

A further revision given in the Appendix, of Section IIC, Part B of the Tentative Definitions D 123 - 44 T, consists of a change in title and the addition of fruit hair fibers and more varieties of cotton to make the list more representative of commercial trade. Section IID has been editorially revised by deletion of certain fibers to form "Section IIE—Vegetable Fibers—Palm and Miscellaneous Fibers."

Subcommittee B-4 on Bleaching, Dyeing and Finishing (W. M. Scott, chairman; J. Robert Bonnar, acting chairman):

This subcommittee is recommending for publication as tentative new proposed Tentative Methods of Test for Evaluating Treated Textiles for Permanence of Resistance to Microorganisms.[3]

The subcommittee also recommends that the present Standard Method of Test for Colorfastness of Colored Textiles to Light (D 506 - 41) be revised and reverted to tentative. The revised method is appended hereto.[4]

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[3] These methods were accepted as tentative by the Society and appear in the 1945 Supplement to Book of of A.S.T.M. Standards, Part III.

[4] These revised methods were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

The subcommittee also recommends that the Standard Method of Test for Colorfastness to Commercial Laundering and to Domestic Washing of Cotton and Linen Textiles (D 435 - 42) be editorially revised as set forth in the Appendix.

The subcommittee recommends that the following tentatives be completely revised: Tentative Methods of Test for Resistance of Textile Fabrics to Microorganisms (D 684 - 42 T)[4] and for Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 - 41 T).[4]

The subcommittee recommends that the following tentatives be continued as tentative:

Tentative Specifications for:

Fire-Retardant Properties of Treated Textile Fabrics (D 626 - 41 T).

Tentative Methods of Test for:

Volumetric Determination of Small Amounts of Copper in Textiles (D 463 - 37 T),
Apparent Fluidity of Dispersions of Cellulose Fibers in Cuprammonium Hydroxide (D 539 - 40 T),
Resistance of Textile Fabrics to Water (D 583 - 40 T),
Evaluating Compounds Designed to Increase Resistance of Fabrics and Yarns to Insect Pests (D 627 - 41 T), and
Identification of Finishes on Textiles (D 683 - 42 T).

Specifications D 626 are undergoing active study. Methods D 463 and D 539 will be submitted to further study. Revisions in Methods D 583, D 627, and D 683 are now under consideration.

The subcommittee is also studying accelerated aging tests for cotton.

Subcommittee C-2 on Papers and Publicity (D. G. Woolf, chairman) arranged for the presentation of the following papers at the October, 1944, meeting:

"Tomorrow's Textiles—Yesterday's Test Methods,"[5] by J. B. Goldberg,

"Factors Influencing the Breaking Strength of Army and Navy Fabrics,"[6] by Werner von Bergen, and

"A Suggested Method for the Thorough Testing of Antiseptic Fabrics,"[7] by Louis C. Barail.

The following papers were presented at meetings at subcommittees or sections:

Subcommittee A-1, Section I:

"The Importance of Various Fiber Properties in American Upland Cotton in Terms of Yarn Strength," by R. W. Webb.

Subcommittee A-1, Section IV:

"Fatigue Testing of Rayon Tire Cord,"[7] by C. B. Budd and Lewis Larrick.

Subcommittee B-5:

"The Preparation of Specifications," by F. S. Steadman,

"The Application of Control Charts to Indigo Washing," by John Hintermaier, and

"Quality Control in the Manufacture of Nylon Shroud Lines," by J. K. Frederick, Jr.

Harold DeWitt Smith presented, in abridged form, his 1944 Edgar Marburg Lecture on "Textile Fibers—An Engineering Approach to an Understanding of Their Properties and Utilization."[8]

This report has been submitted to letter ballot of the committee which consists of 299 members; 146 members returned their ballots, all of whom have voted affirmatively,

Respectfully submitted on behalf of the committee,

H. J. BALL,
Chairman.

W. H. WHITCOMB,
Secretary.

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[5] ASTM BULLETIN, No. 135, August, 1945, p. 47.

[6] This was an abridged presentation of the original paper by Werner von Bergen, John C. Hintermaier, and Eric Ullman, "Factors Influencing the Breaking Strength of Army and Navy Fabrics," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 916 (1944).

[7] ASTM BULLETIN, No. 136, October, 1945.

[8] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 543 (1944); also issued as a separate reprint.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-13 presented to the Administrative Committee on Standards the following recommendations as listed in the report:

New Tentative Methods for:
Evaluating Treated Textiles for Permanence of Resistance to Fungi (D 862 - 45 T).

New Tentative Recommended Practice for:
Yarn Numbering (D 861 - 45 T).

Revision of Tentative Methods for:
Testing Resistance of Textile Fabrics to Microorganisms (D 684 - 45 T),
Testing Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 - 45 T),
Testing Spun, Twisted, or Braided Products Made from Flax, Hemp, Ramie, or Mixtures Thereof (D 739 - 45 T), and
Testing Rope (D 738 - 45 T).

Revision of Tentative Definition for:
Terms Relating to Textile Materials (D 123 - 45 T).

Revision and Reversion to Tentative of Standard Method for:
Testing Colorfastness of Colored Textiles to Light (D 506 - 45 T).

Tentative Revision of Standard Methods for:
Testing Wool Felt (D 461 - 44), and
Testing Single Jute Yarn (D 541 - 41).

These recommendations were accepted by the Standards Committee on January 17, 1946, and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III, under the designations indicated above.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR TEXTILE MATERIALS

In this Appendix are given proposed revisions in certain standards and tentatives covering textile materials which are referred to earlier in this report. These standards and tentatives appear in their present form in the 1944 Book of A.S.T.M. Standards, Part III.

I. NATURAL FIBERS

C. VEGETABLE FIBERS—SEED AND FRUIT HAIR FIBERS.

Commercial and Botanical Name[d]		Staple Length, in.	Geographical Sources
Akund	*Calotropia gigantes*		Asia
COTTON	*Gossypium, various species*		
1. Upland type			
a. American	*Gossypium hirsutum*	$\frac{3}{4}$ to $1\frac{7}{16}$	United States
b. Asiatic	*Gossypium arboreum and Gossypium herbaceum*	$\frac{3}{8}$ to 1	India, China
c. Levant	*Gossypium herbaceum*	$\frac{3}{8}$ to 1	Asia
2. Sea Island type			
a. Sea Island	*Gossypium barbadense*	$1\frac{1}{2}$ to $2\frac{1}{2}$	
Montserrat	*Gossypium barbadense*	$1\frac{1}{2}$ to $1\frac{3}{4}$	British West Indies
St. Vincent	*Gossypium barbadense*	$1\frac{3}{4}$ to $2\frac{1}{2}$	British West Indies
Florida & Georgia	*Gossypium barbadense*	$1\frac{7}{16}$ to $1\frac{5}{8}$	United States
b. American Egyptian	*Gossypium barbadense*		
SxP (Sakel x Pima)	*Gossypium barbadense*	$1\frac{3}{8}$ to $1\frac{5}{8}$	United States
Earlipima	*Gossypium barbadense*	$1\frac{7}{16}$ to $1\frac{5}{8}$	United States
c. Egyptian	*Gossypium barbadense*		
Ashmouni	*Gossypium barbadense*	$1\frac{1}{8}$ to $1\frac{9}{32}$	Egypt
Giza	*Gossypium barbadense*	$1\frac{3}{8}$ to $1\frac{7}{16}$	Egypt
Karnak	*Gossypium barbadense*	$1\frac{3}{8}$ to $1\frac{5}{8}$	Egypt
Others (Sakel, Malaki, Maarad)	*Gossypium barbadense*	$1\frac{3}{8}$ to $1\frac{11}{16}$	Egypt
3. Peruvian	*Gossypium peruvianum*	1 to $1\frac{3}{8}$	Peru
4. American Tree Cotton	*Gossypium purpurescens*		
Marie Galante	*Gossypium purpurescens*	1 to $1\frac{1}{4}$	British West Indies
Moco	*Gossypium purpurescens*	1 to $1\frac{1}{4}$	Brazil
Haiti (Bourbon)	*Gossypium purpurescens*	1 to $1\frac{1}{4}$	Haiti
KAPOK	*Ceiba pentandra*	$\frac{3}{4}$ to $1\frac{1}{4}$	Tropics
MILKWEED FLOSS	*Asclepias, various species*	$\frac{3}{4}$ to $1\frac{1}{4}$	North America
Ozone fiber	*Asclepias sp.*		United States
Paina	*Chorisia species*		South America
Palo	*Chorisia species*		South America
Pochote	*Ceiba aesculifolia*		Mexico
Samohu	*Chorisia species*		South America

[d] Preferred or most common names are in capital letters; botanical names are in italics.

REVISIONS OF TENTATIVES

Tentative Definitions of Terms Relating to Textile Materials (D 123 - 44 T):

In order to provide for the addition of fruit hair fibers and to make the list of cotton varieties more representative of the commercial trade, make the necessary revisions in the present Table II (Natural Fibers), Section C (Vegetable Fibers—Seed Hair Fibers) to agree with the accompanying Table I.

The following definitions are recommended for publication as tentative:

Duck, n.—A comparatively firm, heavy, plain weave cotton fabric, weight per square yard 6 to 50 oz. There are two general types of duck based on construction:

1. Regular Duck, in which both the warp and filling yarns are plied and unsized, such as numbered, army, hose, and belting duck.
2. Flat Duck, in which the warp yarns are single, sized, with two strands of yarn woven as one warp end, interlacing as a unit with one filling yarn which is either single or plied.

Length, Breaking (Critical Length, Maximum Length) *n.*—A calculated measure of yarn strength. The calculated length of a yarn which has just sufficient mass to break of its own weight.

Nylon, n.—A generic term for any long-chain synthetic polymeric amide which has recurring amide groups as an integral part of the main polymer chain, and which is capable of being formed into a filament in which the structural elements are oriented in the direction of the axis.

Nylon, Textile, n.—Fibers, filaments, yarns, and related forms of nylon, suitable for spinning, knitting, weaving, braiding, or other textile operations.

Wool, n.—The fibers from the fleece of the sheep or lamb, or hair of the angora or cashmere goat (and may include the so-called specialty fibers from the hair of the camel, alpaca, llama, and vicuna) which have never been reclaimed from any woven or felted wool product.

Yarn Intermediates, n.—A generic term for products obtained during the conversion of fibers to yarns, including card webs, laps, slivers, rovings, tops, etc.

Tentative Methods of Testing and Tolerances for Rope (Leaf and Bast Fibers) (D 738 - 43 T):

Section 11.—Change the title and revise this section from its present form to read as follows by the addition of the italicized words and the omission of the words in brackets:

11. *Ethylene Dichloride Extract:* (*a*) *Test Specimens.*—Two conditioned test specimens (Section 5) of *approximately* 2 g. each shall be [weighed] *taken* from each sample obtained in accordance with Section 4 [Record the weight of the conditioned specimens as weight *E*.] *and accurately weighed to the nearest 1 mg., weight E.*

(*b*) *Procedure.*—Each *conditioned* test specimen (Paragraph (*a*)) shall be extracted separately in a Soxhlet apparatus, until the liquid in the extraction tube is *colorless and* clear, siphoning not less than 20 times with ethylene dichloride (boiling point 82.5 to 84 C., acidity less than 0.001 per cent) (Note 1). The extraction apparatus (Note 2) shall be of sufficient capacity to hold the specimen easily. The opening in the extraction tube shall be protected by a filter, free from extractable matter, such as a filter thimble, a wrapping of filter paper, or a thin layer of cotton or glass wool. The solvent shall then be evaporated from the extract *until the odor of the solvent disappears,* the residue dried at 100 to 105 C., and cooled to room temperature in a desiccator. The residue shall then be weighed to the nearest 1 mg. The residue shall be returned to the oven and the drying, cooling, and weighing *operations* shall be repeated until [there is no progressive change in weight] *the loss in weight is less than 1 per cent of the weight of the residue in 1 hr. of heating.* The residue consists of [oils, fats, waxes, pitch, asphalt, tar] *oil, wax,* and components of the natural fiber extractable by the solvent. Record the dry weight of the extract as weight *F.*

NOTE 1.—C.p. carbon tetrachloride, U.S.P. diethyl ether, *c.p. chloroform,* c.p. benzene, or any petroleum fraction distilling between 38 and 100 C. may be substituted for ethylene dichloride.

NOTE 2.—The type of extraction apparatus described in the Standard Methods of Testing and Tolerances for Knit Goods (A.S.T.M. Designation: D 231) may be used.

(*c*) *Calculations.*—The content of oily and fatty substances *of each specimen* shall be *separately* calculated as a percentage of the original conditioned weight of the specimen by the following formula:

$$W = \frac{100\ F}{E}$$

where:

W = percentage of oils, fats, [waxes], tars, etc. (conditioned basis),

E = weight of conditioned specimen (Paragraph (*a*)), and

F = weight of dry extract (Paragraph (*b*)).

(*d*) *Report.—The percentage content of extractable matter for the shipment shall be the average of the percentage extracts of the specimens tested.*

Tentative Methods of Testing and Tolerances for Spun, Twisted, or Braided Products Made from Flax, Hemp, Ramie, or Mixtures Thereof (D 739 - 43 T):

Section 23.—Change the title and revise this section from its present form to read as follows:

23. *Ethylene Dichloride Extract* (*a*) *Test Specimens.*—Two freshly conditioned specimens (Section 21(*a*)) shall be weighed accurately to the nearest 1 mg., weight *E.*

(*b*) *Procedure.*—Each conditioned test specimen (Paragraph (*a*)) shall be extracted separately in a Soxhlet apparatus until the liquid in the extraction tube is colorless and clear, siphoning not less than 20 times with ethylene dichloride (boiling point 82.5 to 84 C., acidity less than 0.001 per cent) (Note 1). The extraction apparatus (Note 2) shall be of sufficient capacity to hold the specimen easily. The opening in the extraction tube shall be protected by a filter, free from extractable matter, such as a filter thimble, a wrapping of filter paper, or a thin layer of cotton or glass wool. The solvent shall then be evaporated from the extract until the odor of the solvent disappears, the residue dried at 100 to 105 C., and cooled to room temperature in a desiccator. The residue shall then be weighed to the nearest 1 mg. The residue shall be returned to the oven and the drying, cooling, and weighing operations shall be repeated until the loss in weight is less than 1 per cent of the weight of the residue in 1 hr. of heating. The residue consists of oil, wax, and components of the natural fiber extractable by the solvent. Record the dry weight of the extract as weight *F*.

NOTE 1.—C.p. carbon tetrachloride, U.S.P. diethyl ether, c.p. chloroform, c.p. benzene, or any petroleum fraction distilling between 38 and 100 C. may be substituted for ethylene dichloride.

NOTE 2.—The type of extraction apparatus described in the Standard Methods of Testing and Tolerances for Knit Goods (A.S.T.M. Designation: D 231) may be used.

(*c*) *Calculations.*—The content of oil and fatty substances of each specimen shall be separately calculated as a percentage of the original conditioned weight of the specimen as follows:

$$W = \frac{100\,F}{E}$$

where:

W = percentage of oils, fats, tars, etc. (conditioned basis),
E = weight of conditioned specimen (Paragraph (*a*)), and
F = weight of dry extract (Paragraph (*b*)).

(*d*) *Report.*—The percentage content of extractable matter for the shipment shall be the average of the percentage extracts of the specimens tested.

TENTATIVE REVISIONS OF STANDARDS

Standard Methods of Testing and Tolerances for Single Jute Yarn (D 541 – 41):

Section 11.—Delete this section and renumber subsequent sections accordingly.

Section 16.—Change from its present form to read as follows:

16. *Ethylene Dichloride Extract:* (*a*) *Test Specimens.*—A specimen of approximately 10 g. shall be drawn from each of ten tubes, conditioned as prescribed in Section 8 and each shall then be weighed accurately to the nearest 1 mg., weight *E*.

(*b*) *Procedure.*—Each conditioned test specimen (Paragraph (*a*)) shall be extracted separately in a Soxhlet apparatus, until the liquid in the extraction tube is colorless and clear, siphoning not less than 20 times with ethylene dichloride (boiling point 82.5 to 84 C., acidity less than 0.001 per cent (Note 1). The extraction apparatus (Note 2) shall be of sufficient capacity to hold the specimen easily. The opening in the extraction tube shall be protected by a filter, free from extractable matter, such as a filter thimble, a wrapping of filter paper, or a thin layer of cotton or glass wool. The solvent shall then be evaporated from the extract until the odor of the solvent disappears, the residue dried at 100 to 105 C., and cooled to room temperature in a desiccator. The residue shall then be weighed to the nearest 1 mg. The residue shall be returned to the oven and the drying, cooling, and weighing operations shall be repeated until the loss in weight is less than 1 per cent of the weight of the residue in 1 hr. of heating. The residue consists of oil, wax, and components of the natural fiber extractable by the solvent. Record the dry weight of the extract as weight *F*.

NOTE 1.—C.p. carbon tetrachloride, U.S.P. diethyl ether, c.p. chloroform, c.p. benzene, or any petroleum fraction distilling between 38 and 100 C. may be substituted for ethylene dichloride.

NOTE 2.—The type of extraction apparatus described in the Standard Methods of Testing and Tolerances for Knit Goods (A.S.T.M. Designation: D 231) may be used.

(*c*) *Calculations.*—The content of oily and fatty substances of each specimen shall be separately calculated as a percentage of the original conditioned weight of the specimen by the following formula:

$$W = \frac{100\,F}{E}$$

where:

W = percentage of oils, fats, tars, etc. (conditioned basis),
E = weight of conditioned specimen (Paragraph (*a*)), and
F = weight of dry extract (Paragraph (*b*)).

(*d*) *Report.*—The percentage content of extractable matter for the shipment shall be the average of the percentage extracts of the specimens tested.

Standard Methods of Testing Wool Felt (D 461 – 44):

Title.—Change to read as follows by the omission of the word in brackets:

Standard Methods of Testing [Wool] Felt.

Section 1 (a).—Change to read as follows:

1. (*a*) These methods of test are applicable to felt. Felt is a fabric built up by the interlocking of fibers by a suitable combination of mechanical work, chemical action, moisture, and heat, without spinning, weaving, or knitting. Felt may consist of one or more classes of fibers, wool, reprocessed wool, and reused wool, with or without admixture with animal, vegetable, and synthetic fibers.[a]

[a] The terms, *wool, reprocessed wool,* and *reused wool* are defined essentially in accordance with the Wool Products Labeling Act, 1939, as follows:

Wool.—The term "wool" means the fiber from the fleece of the sheep or lamb, or hair of the angora or cashmere goat (and may include the so-called specialty fibers from the hair of the camel, alpaca, llama, and vicuna) which has never been reclaimed from any woven or felted wool product.

Reprocessed Wool.—The term "reprocessed wool" means the resulting fiber when wool has been woven or felted into a wool product which, without ever having been utilized in any way by the ultimate consumer, subsequently has been made into a fibrous state.

Reused Wool.—The term "reused wool" means the resulting fiber when wool or reprocessed wool has been spun, woven, knitted, or felted into a wool product which, after having been used in any way by the ultimate consumer, subsequently has been made into a fibrous state.

New Section 3.—Add a new Section 3 on sampling to read as follows, renumbering the subsequent sections accordingly:

3. *Sampling.*—Samples shall be cut back from the end of the felt a distance equal to the width of the piece in the case of roll felt, and 6 in. from the edge in the case of sheet felt. Test specimens, unless otherwise noted, shall be taken from the sample at the center and near both edges so as to be representative of the felt over its entire width. No specimen shall be taken within 6 in. of any pin holes or finished outer edge. When required, samples shall be legibly marked with indelible ink or by other means to indicate the lengthwise and widthwise direction in the original piece.

Section 7.—Renumber as Section 8, and change to read as follows:

8. A representative specimen containing not less than 40 sq. in. shall be cut from the felt in accordance with Section 2. The specimen shall be conditioned in accordance with Section 3 and then weighed on a balance sensitive to 0.1 per cent of the total weight. The weight shall be expressed in ounces per square yard.

New Sections.—Add new sections 19 and 20 to read as follows:

Determination of Air Resistance of Filter Felts

19. (*a*) *Scope.*—This method of test covers the procedure for determining directly the air flow resistance of filter felts.

(*b*) *Apparatus.*—The apparatus shall consist essentially of a suction fan or other means for drawing air through the test specimen, a circular orifice of known area over which the felt is clamped, a means of measuring the volume of air flow through the felt, a means of adjusting the air flow to a known amount, and a manometer for measuring the pressure drop across the specimen of felt. The test area of the circular orifice over which the felt is clamped shall be not less than 10 sq. in. and shall be known within an accuracy of 1 per cent. The clamp shall effectively eliminate edge leakage and shall be such that it does not interfere with the flow of air through the test area. The apparatus shall be calibrated directly with a calibrated gasometer and shall be capable of measuring air flow accurately to within 1 per cent. The apparatus shall be capable of testing felt up to $\frac{1}{4}$ in. in thickness over a range of filtration rates from 1 to 300 cu. ft. per sq. ft. per min.

(*c*) *Test Specimen.*—At least five test specimens shall be taken at separate locations on the sample so that the test results will be representative.

(*d*) *Conditioning.*—The specimens shall be conditioned in accordance with Section 3 before testing.

(*e*) *Procedure.*—The test specimen shall be mounted between the clamp and the circular orifice with sufficient tension to draw the felt smooth. It shall not be distorted in its own plane. Edge leakage shall be checked at the specified filtration rate by inserting a pliable impervious septum, such as soft rubber sheeting, between the clamp or orifice flange and the upstream surface of the felt with the pressure-drop manometer line closed. There shall be no measurable flow through the apparatus. In the absence of edge leakage, conditioned air shall be drawn through the known area of the felt and through the calibrated flowmeter at the required filtration rate. The pressure drop across the felt shall then be recorded from the manometer to the nearest 0.01 in. of water.

(*f*) *Report.*—The air flow resistance of the filter felt shall be expressed as the pressure drop in inches of water at the required filtration rate. The average of the test results obtained on five specimens or at five different locations on the felt shall be reported.

DETERMINATION OF WATER ABSORPTION OF FELT[1]

20. (*a*) *Apparatus.*—The apparatus shall consist essentially of an immersion tank (Fig. 1), sinkers, blotters, and a hand roller weighing 1 kg. (2.2 lb.) (Fig. 2). The blotters shall conform to the following requirements:

(*1*) *Absorbency*, 1 ml. of standard Government Ink (Note) in 40 to 50 sec.,

(*2*) *Caliper*, 26 to 26.5 points, and

(*3*) *Bursting Strength* (Mullen), 40 to 45 psi. determined in accordance with the Tentative Method of Test for Bursting Strength of Paper (A.S.T.M. Designation: D 774).

NOTE.—The ink shall conform to the Federal Specification for Ink; Writing (TT-I-563a). Blotting paper "24 x 19-120 Buff Sterling Blotting" of the Standard Paper Mfg. Co., Richmond, Va., or its equivalent, will conform to the requirements specified.

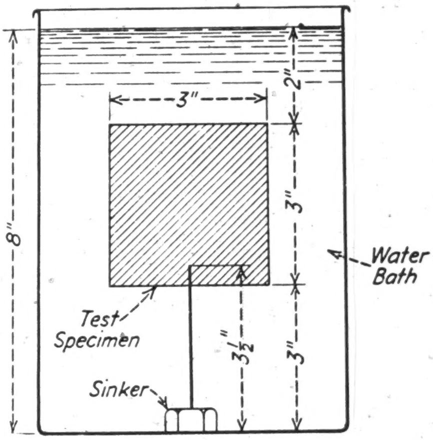


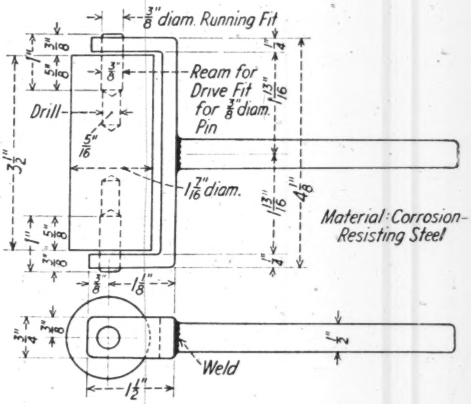
FIG. 1.—Immersion Tank for Water Absorption Test.

(*b*) *Conditioning.*—The felt to be tested shall be conditioned in accordance with Section 3.

(*c*) *Test Specimens.*—Three test specimens, each 3 in. square, shall be cut from the conditioned felt and weighed to the nearest 5 mg., weight *A*.

(*d*) *Procedure.*—A sinker shall be attached to the weighed specimen by means of a wire hook at a point midway between two sides and 0.5 in. from the edge (Fig. 1) and the specimen dropped into the immersion tank containing distilled water at a temperature of 70 F. (21 C.). The sinker shall be heavy enough to sink to the bottom of the tank. The depth of water in the tank shall be adjusted so that the test specimen is immersed under an average hydrostatic head of 3.5 in. (Note). After immersion for 60 min. the specimen shall be removed from the water, immediately placed between two 7 by 8-in. pieces of dry blotting paper, after detaching the sinker, and then rolled once over and back with the hand roller. The specimen shall be quickly reweighed to the nearest 5 mg. immediately after the rolling operation, weight *B*.

NOTE.—The requirement for depth of immersion will be met if the water in the tank is 8 in. in depth and the sinker measures 3½ in. from the lower end to the top of the hook, as shown in Fig. 1.



NOTE.—The parts shall be weighed separately before assembling and the weight adjusted by drilling 5/16-in. holes along the axis of the roller to bring the total weight of the assembly to 1 kg. (2.2 lb. or 35¼ oz.).

FIG. 2.—Hand Roller for Water Absorption Test.

(*e*) *Calculation.*—The water absorption shall be calculated as a percentage of the original conditioned weight, as follows:

$$\text{Water absorption, per cent} = \frac{B - A}{A} \times 100$$

where:

A = weight of conditioned specimen (Paragraph (*c*)), and

B = weight of specimen after immersion (Paragraph (*d*)).

(*f*) *Report.*—Report the average of the results obtained on three specimens as the percentage of water absorption.

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[1] This method is based on the procedure developed by the Research Committee of the American Association of Textile Chemists and Colorists.

ADOPTION OF TENTATIVE AS STANDARD

Tentative Definitions of Terms Relating to Textile Materials (D 123 – 44 T):

The committee recommends for adoption as standard and incorporation in the Standard Definitions of Terms Relating to Textile Materials (D 123 – 44), the following three definitions revised by the addition of the italicized words and the omission of the words in brackets:

Turn, *n.* [Cordage] *Rope.*—The distance parallel to the axis of a rope in which a strand makes one complete spiral.

Yarn, Cross-Blended, *n.*—A *single* yarn spun from a blend or mixture of different fiber species [in a single series of operations].

EXAMPLE.—A yarn spun from cotton fibers and rayon staple, or from wool fibers and acetate staple, or from wool and cotton fibers.

Yarn, Self-Blended, *n.*—A *single* yarn spun from a blend or mixture of the same fiber species [in a single series of operations].

EXAMPLE.—A spun rayon yarn produced from staple of different lengths or different deniers.

EDITORIAL CHANGES IN STANDARD

Standard Method of Test for Colorfastness to Commercial Laundering and to Domestic Washing of Cotton and Linen Textiles (D 435 – 42):

Section 1.—In the second sentence after "low temperature" add "(105 F.)"; also after "hot" add "(182 F.)."

Section 2.—In the last sentence change the reference to "special rubber balls" to read "$\frac{1}{4}$-in. steel balls (stainless) or Monel metal." Omit the reference to rubber balls in the accompanying foot note to this section.

Section 4.—Delete this section (including the note) and replace it with the following:

4. The following standard dyeings may be used in each test as a guide as to what constitutes satisfactory colorfastness of the specimens tested. They shall be tested at the same time and in the same manner as the specimens of material being tested for colorfastness.

C.W. 1.—A 2 per cent dyeing of Diamine Fast Blue FFB Pr. 71 (For use in Test No. 1)

C.W. 2.—A 4 per cent dyeing of Primuline concentrated, Color Index 812. Diazotized and developed with Beta Naphthol (For use in Test No. 2)

C.W. 3.—A 2 per cent dyeing of Vat Blue 2BD 100 per cent powdered, Color Index 1184 (For use in Test No. 3)

C.W. 4.—A 2.5 per cent dyeing of a Vat Violet BN 100 per cent powdered, Color Index 1163. (For use in Test No. 4)

NOTE 1.—*Standard C.W. 1* represents a grade of dyeing that must be washed carefully and at quite a low temperature. This grade is unsuitable for use as trimmings and should not be washed with other garments liable to be injured by a slight amount of staining. Washing temperatures should be below 100 F. and there is likely to be a slight loss of shade with each successive washing.

Standard C.W. 2 represents a materially lower degree of fastness than C.W. 4 or C.W. 3. It is less fast to chlorine and distinctly less fast to washing at high temperature. It does not lose much in shade, but is liable to stain white fabric if the washing temperature goes above 120 F.

Standard C.W. 3 represents a slightly lower degree of fastness than C. W. 4, mainly as regards fastness to chlorine.

Standard C.W. 4 represents the highest degree of fastness and does not lose in shade or stain white cloth if repeatedly subjected to normal laundry treatment.

NOTE 2.—These standard dyeings are prepared according to the standard dyeing procedures described in the current Yearbook of the American Association of Textile Chemists and Colorists, and may be purchased from the Chairman, Research Committee, A.A.T.C.C., Lowell Textile Institute, Lowell, Mass.

REPORT OF COMMITTEE D-14

ON

ADHESIVES*

In view of requests from industry for standards applying to the field of adhesives and the demand and interest expressed, the Executive Committee, after a canvass of interested organizations, authorized the appointment of a Committee on Adhesives. Committee D-14 on Adhesives was formally organized at a meeting held in Philadelphia, Pa. on June 20, 1944 with the following scope of activities:

Scope.—The formulation of specifications, methods of test, and definitions of terms pertaining to adhesives, including animal, vegetable, mineral, and synthetic types.

At the organization meeting, the following temporary officers were elected:

T. R. Truax, Temporary Chairman.

P. H. Bilhuber, Temporary Vice-Chairman.

Henry Grinsfelder, Temporary Secretary.

The members of the committee represent the leading producers and consumers of adhesives, the present classification of the membership[1] being as follows: 29 producers, 23 consumers, 7 general interests and 1 unclassified member. In order to cover the field adequately, the following subcommittees were organized under the chairmanship of the individuals indicated:

Subcommittee I on Strength Properties
Chairman: M. H. Bigelow, Chemical Warfare Service
Subcommittee II on Analytical Tests
Chairman: Leonard Repsher, Bakelite Corp.
Subcommittee III on Permanency
Chairman: F. J. Wehmer, Minneapolis Mining and Mfg. Co.
Subcommittee IV on Working Qualities
Chairman: C. B. Hemming, United States Plywood Corp.
Subcommittee V on Specifications
Chairman: Gerald Reinsmith, Office Chief of Ordnance
Subcommittee VI on Nomenclature
Chairman: G. M. Kline, National Bureau of Standards

During the year all the subcommittees initiated work in their respective fields and Subcommittees I, II, III, and IV held scheduled meetings.

The Advisory Committee, consisting of the temporary officers, two members-at-large, and the subcommittee chairmen, held two meetings during the year—on June 20, 1944, and on January 9, 1945. At the January meeting action was taken on a number of applications for membership and suggestions were received as to proposed additional members. Also proposed by-laws for the committee were prepared which have since been approved by letter ballot vote of the committee, and plans were formulated for a Symposium on Adhesives.

The committee for planning and developing the symposium on Adhesives consists of the six subcommittee chairmen. The subjects for the symposium will be concerned with methods of testing adhesives, the need for their preparation, their character and scope, what has been done in the past, and what is planned for the future.

While the work of the subcommittees

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] 1944 A.S.T.M. Year Book, pp. 299 and 300.

during the year did not result in the development of approved tests or completed specifications for adhesives, considerable progress was made in reviewing and compiling existing information and in developing, perfecting, and checking test methods.

This report has been submitted to letter ballot of the committee which consists of 60 members; 52 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

T. R. TRUAX,
Temporary Chairman.

HENRY GRINSFELDER,
Temporary Secretary.

REPORT OF COMMITTEE D-16

ON

INDUSTRIAL AROMATIC HYDROCARBONS*

Committee D-16 on Industrial Aromatic Hydrocarbons was organized the latter part of 1943, and held its first general meeting on June 28, 1944, in New York, N. Y., during the 1944 Annual Meeting of the Society.

The following statement of scope of the work of the committee has been adopted:

> *Scope.*—Nomenclature, specifications and methods of test for industrial aromatic hydrocarbons having boiling points below approximately 210 C. (410 F.) and which are used for the manufacture of chemicals or as solvents.

The following officers were elected in June, 1944:

Chairman, J. M. Weiss.
Vice-Chairman, V. J. Altieri.
Secretary, R. P. Anderson.

The committee regrets the resignation (due to retirement) of its secretary, Dr. Anderson, effective January 1, 1945. W. L. Douthett has been elected as his successor.

The committee consists of 33 members, of whom 15 are classified as producers, 15 consumers, and 3 as general interest members.

At the June, 1944, meeting several methods of test and specifications developed by the subcommittees were recommended for publication as information as a means of securing constructive suggestions for their improvement looking toward their submittal for publication as tentative. Numerous comments have been received and studied, and appropriate action was taken through correspondence and at a meeting of the Advisory Committee held in New York, N. Y., on April 6, 1945.

The various proposals of the five subcommittees reporting have been based on tests and specifications employed in the aromatic chemical and aromatic solvent field for many years, although to this date they have not been standardized by A.S.T.M. These recommendations have been made in order adequately to cover the requirements for the specifications and methods of test believed essential to control quality of products for the aromatic chemical and solvent manufacturers and consumers. The specifications primarily cover aromatic hydrocarbons derived from coal tar but will be modified or augmented, if necessary, if and when these products as such are generally available from petroleum. Cognizance has also been taken of present A.S.T.M. standard procedures and specifications likely to conflict with those believed necessary for proper use by Committee D-16 and, where necessary, cooperative efforts with committees having jurisdiction over the method of test or specifications in question have and will be made.

NEW TENTATIVES

The committee is submitting seven new methods of test and twelve new specifications for publication as tentative as listed in Table I. They are appended hereto[1] and are further referred to in the reports of the responsible subcommittees.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] These methods and specifications were accepted as tentative by the Society and appear in the 1945 Supplement to Book A.S.T.M. Standards, Part III.

These recommendations have been submitted to letter ballot of the committee, which consists of 33 voting members; 29 members returned their ballots with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
NEW TENTATIVES			
Test for Specific Gravity, Color, and Hydrogen Sulfide and Sulfur Dioxide Content (Qualitative) of Industrial Aromatic Hydrocarbons	26½	1½	1
Test for Distillation of Industrial Aromatic Hydrocarbons[a]	25	3	1
Test for Acid Wash Color of Benzene, Toluene, Xylene, and Similar Industrial Aromatic Hydrocarbons	27	0	2
Test for Acidity of Benzene, Toluene, Xylene, and Similar Industrial Aromatic Hydrocarbons	26	2	1
Test for Solidifying Point of Benzene	28	0	1
Test for Paraffins in Industrial Aromatic Hydrocarbons	26	0	3
Test for Copper Corrosion of Industrial Aromatic Hydrocarbons	28	0	1
Spec. for Nitration Grade Benzene	24	1	1
Spec. for Industrial Grade Benzene	24	1	1
Spec. for Nitration Grade Toluene	23	2	1
Spec. for Industrial Grade Toluene	24	1	1
Spec. for Nitration Grade Xylene	24	1	1
Spec. for Five-Degree Xylene	24	1	1
Spec. for Ten-Degree Xylene	25	1	1
Spec. for Industrial Grade Xylene	25	1	1
Spec. for Industrial 90 Benzene	26	1	0
Spec. for Refined Solvent Naphtha	25	1	1
Spec. for Crude Light Solvent Naphtha	24	1	2
Spec. for Crude Heavy Solvent Naphtha	24	1	2

[a] The classified vote on the new tentative Method of Test for Distillation of Industrial Aromatic Hydrocarbons was as follows: Affirmative: 12 producers, 11 consumers, 2 general interests: negative: 2 producers, 1 consumer.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Test for Crude Aromatic Products (D. F. Gould, chairman).—This subcommittee has in preparation for publication as tentative a Method of Test for Refined Water-White Constituents in Light Oil. Other activities of this subcommittee include the development of methods of sampling, in conjunction with Subcommittee II, and the consideration of improved means of evaluating crude aromatic products.

Subcommittee II on Methods of Test for Refined Aromatic Products (V. J. Altieri, chairman).—Considerable activity on the part of this subcommittee resulted in the recommendation of the following methods of test for publication as tentative:

Methods of Test for:

Specific Gravity, Color, and Hydrogen Sulfide and Sulfur Dioxide Content (Qualitative) of Industrial Aromatic Hydrocarbons,
Distillation of Industrial Aromatic Hydrocarbons,
Acid Wash Color of Benzene, Toluene, Xylene, and Similar Industrial Aromatic Hydrocarbons,
Acidity of Benzene, Toluene, Xylene, and Similar Industrial Aromatic Hydrocarbons,
Solidifying Point of Benzene,
Paraffins in Industrial Aromatic Hydrocarbons, and
Copper Corrosion of Industrial Aromatic Hydrocarbons.

This subcommittee has conducted cooperative distillation tests to evaluate the Proposed Tentative Method listed above in relation to three forms of apparatus. The results of these cooperative tests on industrial 90 benzene, industrial pure benzene, industrial pure toluene, nitration grade toluene, industrial grade xylene, and nitration grade xylene appear in Appendix I.[2]

Subcommittee II, through its Group I on Sampling (C. B. Francis, chairman), in conjunction with Subcommittee I, has reviewed existing standard practice in the field of sampling, and has prepared preliminary Proposed Tentative Methods of Sampling Crude and Refined Industrial Aromatic Hydrocarbons. This work now is in the established channels designed to evolve appropriate methods of sampling.

Subcommittee III on Specifications for Aromatic Chemicals (J. N. Wickert, chairman).—This subcommittee has recommended the following specifications for publication as tentative:

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[2] See p. 340.

Specifications for:
Nitration Grade Benzene,
Industrial Grade Benzene,
Nitration Grade Toluene,
Industrial Grade Toluene,
Nitration Grade Xylene, and
Five-Degree Xylene.

Specifications for additional aromatic chemical products will be considered.

Industrial grade toluene is now covered by the A.S.T.M. Specifications for Industrial Pure Toluene (Toluol) (D 362 - 36) but for aromatic chemical use, different quality is required and the matter of jurisdiction is now being discussed with Committee D-1 on Paint, Varnish, Lacquer, and Related Products.

Subcommittee IV on Specifications for Aromatic Solvents (R. F. Ruthruff, chairman).—This subcommittee has developed and recommended the following aromatic solvent specifications for publication as tentative:

Specifications for:
Ten-Degree Xylene,
Industrial Grade Xylene,
Industrial 90 Benzene,
Refined Solvent Naphtha,
Crude Light Solvent Naphtha, and
Crude Heavy Solvent Naphtha.

Industrial 90 benzene and industrial xylene are now covered by A.S.T.M. Specifications for Industrial 90 per cent Benzene (Benzol) (D 361 - 36) and for Industrial Xylene (Xylol) or Solvent Naphtha (D 364 - 36), respectively, and steps have been taken to adjust differences with Committee D-1 which has had jurisdiction over these two standards.

Realizing that the specifications for aromatic solvents, referred to above, are more or less similar to the specifications developed and utilized by the coal-tar industry over a considerable period of time, and that such materials from petroleum may be a factor in the future, a Special Committee on Aromatic Petroleum Solvents (W. H. Bahlke, chairman) from this subcommittee was appointed to investigate, determine, and report the types of aromatic hydrocarbons and solvents which the petroleum industry intends to produce in the post-war period so that an effort can be made at least to initiate the preparation of suitable specifications for such materials. It was concluded by this group that any attempts to standardize at this time on specifications for aromatic chemicals and solvents from petroleum would be premature and perhaps lead to undue complications. A report of this special committee appears in Appendix II.[3]

Subcommittee V on Nomenclature (J. Bennett Hill, chairman).—This subcommittee has been faced with the question of whether to use the terminology "benzol," "toluol," etc., or the terminology ending with the suffix "-ene." The decision has been that the preferred usage is the "-ene" suffix and this nomenclature has been adopted for committee publications.

This report has been submitted to letter ballot of the committee which consists of 33 voting members; 21 members returned their ballots, of whom 19 have voted affirmatively, and 1 negatively.

Respectfully submitted on behalf of the committee,

J. M. WEISS,
Chairman.

W. L. DOUTHETT,
Secretary.

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[3] See p. 348.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 10, the recommendations affecting tentatives referred to in the report were submitted by Committee D-16 and accepted by the Administrative Committee on Standards on June 27, 1945. The new tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

APPENDIX I

COOPERATIVE DISTILLATION TESTS

At the meeting of Committee D-16 held on June 28, 1944, it was recommended that cooperative distillation tests should be undertaken to evaluate the Proposed Tentative Method of Test for Distillation of Industrial Aromatic Hydrocarbons.[1]

A series of tests by nine cooperating laboratories was accordingly arranged by Group 3 under the chairmanship of D. F. Gould, of Subcommittee II on Methods of Test for Refined Aromatic Products.

In these tests comparisons were made of the following forms of apparatus:

(*1*) The apparatus specified in the Proposed Tentative Method,

(*2*) The apparatus specified in the Proposed Tentative Method modified by use of the condenser and shield described in A.S.T.M. Method D 86, and

(*3*) The 250-ml. Saybolt flask specified in A.S.T.M. Method D 158, the condenser and receiver described in A.S.T.M. Method D 86, and the Solvents Distillation thermometers 40 C – 44 T and 41 C – 44 T from A.S.T.M. Specifications E 1.[2]

Samples of industrial 90 benzene, industrial grade benzene, industrial grade toluene, nitration grade toluene, industrial grade xylene, and nitration grade xylene, were distributed to and tested by the cooperating laboratories. The results obtained are shown in Tables I to VI. The following notes should be considered in connection with these results:

Sun Oil Co—The thermometer specified in Method I was used throughout. Heating was done by means of an electric heater, and the data were not corrected.

Standard Oil Development Co.—An electric heater was used in Methods 2 and 3. Results are uncorrected.

Carnegie-Illinois Steel Corp.—This laboratory used its own thermometer (70 to 150 C.) throughout the tests.

On distillation tests of materials of this character, it is to be expected that temperatures at the 50 per cent point should be reasonably constant and, in the case of pure grades of individual hydrocarbons should lie close to the true boiling point of that hydrocarbon. In view of the discrepancies at the 50 per cent point, it seemed advisable to recalculate the data to a uniform temperature at the 50 per cent point for more accurate comparisons of the methods. For example, in the results for Method I on nitration toluene, in two cases the observed temperatures did not reach the specified boiling point of toluene. Average temperatures corrected in this manner are given in Table VII.

The variations in results of the several laboratories naturally are less when the corrected data are used. The variation in the results are least and the accuracy is best when comparison is made between laboratories which have considerable experience in the testing of relatively pure hydrocarbons such as nitration grade toluene. It is apparent that there is too much variation in start and dry point temperatures. In situations where the known sources of error are not eliminated, it is known that serious errors occur when the thermometer used does not conform with the essential requirements given in the proposed tentative method. One of the most important of these requirements concerns the design and location of the contraction chamber of the thermometer. Consequently, the proposed tentative method has been designed to the end that operators using properly selected equipment may acquire the skill needed to obtain the accuracy and precision[3] given in the specifications.

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[1] This method was accepted as tentative by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[2] 1944 Book of A.S.T.M. Standards, Part III.

Respectfully submitted on behalf of Subcommittee II,

V. J. ALTIERI,
Chairman.

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[3] Accuracy refers to the degree of concordance between the results and the true value. Precision refers to the numeric measure of the reliability after eliminating known sources of error and indicates the reproducibility of the procedure used by a skillful and careful operator.

TABLE I.—DISTILLATION TESTS OF INDUSTRIAL 90 BENZENE.

Distillation Points	Temperature, deg. Cent.					
	Start	5 per cent	50 per cent	90 per cent	95 per cent	Dry Point
METHOD 1—PROPOSED TENTATIVE METHOD						
Shell (A)	81.6	82.3	84.1	94.6	105.8	112.0
Shell (B)	81.6	82.2	84.2	95.4	105.3	>120.0
Std. Oil of Indiana	81.4	82.2	84.2	95.1	107.0	114.3
Carnegie—Illinois	80.8	82.2	84.0	96.5	....	115.4
Jones & Laughlin	80.9	82.3	84.1	94.1	....	115.7
Texas Co.	81.0	82.2	84.1	95.2	99.6	115.2
Sun Oil	80.8	82.2	84.3	95.9	111.3	114.0
Std. Oil Devel. Co.	81.0	82.2	84.2	93.8	105.0	114.5
Eastern Gas	81.0	82.0	84.2	95.6	....	113.9
Barrett	81.0	82.3	84.1	93.5	104.4	113.0
Minimum	80.8	82.0	84.0	93.5	99.6	112.0
Maximum	81.6	82.3	84.3	96.5	111.3	>120.0
Average	81.1	82.24	84.15	95.07	105.49	114.85
METHOD 2—A.S.T.M. METHOD D 86, MODIFIED BY USE OF FLASK AND THERMOMETER SPECIFIED IN METHOD 1						
Shell (A)	....	....	....	....	....	....
Shell (B)	....	....	....	....	....	....
Std. Oil of Indiana	81.2	82.4	84.2	94.2	104.9	114.6
Carnegie—Illinois	80.7	82.1	84.0	96.5	....	115.6
Jones & Laughlin	81.0	82.1	83.9	94.6	....	116.7
Texas Co.	80.4	81.4	83.4	92.8	103.4	115.8
Sun Oil	80.6	82.2	84.3	96.1	111.0	114.0
Std. Oil Devel. Co.	80.8	82.2	84.3	94.3	105.8	114.5
Eastern Gas	80.9	82.2	84.3	94.5	103.7	113.6
Barrett	80.8	82.2	84.0	92.8	103.5	113.6
Minimum	80.4	81.4	83.4	92.8	103.4	113.6
Maximum	81.2	82.4	84.3	96.5	111.0	116.7
Average	80.80	82.10	84.05	94.45	105.38	114.80
METHOD 3—A.S.T.M. D 158 FLASK, A.S.T.M. D 86 CONDENSER AND RECEIVER, E I (40C-44T) AND E I (41C-44T) THERMOMETERS						
Shell (A)	81.4	82.3	84.3	93.8	103.6	114.8
Shell (B)	81.2	82.2	84.2	94.0	103.4	119.6
Std. Oil of Indiana	81.4	82.3	84.2	94.2	104.3	114.4
Carnegie—Illinois	81.1	82.0	84.4	96.0	....	113.3
Jones & Laughlin	81.1	82.1	83.9	96.9	....	116.9
Std. Oil Devel. Co.	80.6	81.9	84.0	94.0	105.1	113.7
Barrett	80.4	81.6	83.5	93.6	104.5	114.2
Minimum	80.4	81.6	83.5	93.6	103.4	113.7
Maximum	81.4	82.3	84.4	96.9	105.1	119.6
Average	81.03	82.06	84.07	94.64	104.20	115.27

TABLE II.—DISTILLATION TESTS OF INDUSTRIAL GRADE BENZENE.

Distillation Points	Temperature, deg. Cent.					
	Start	5 per cent	50 per cent	90 per cent	95 per cent	Dry Point
METHOD 1—PROPOSED TENTATIVE METHOD						
Shell (A)	78.5	79.8	80.0	80.1	80.2	80.3
Shell (B)	79.6	79.9	80.0	80.1	80.2	80.4
Std. Oil of Indiana	79.5	79.8	80.1	80.1	80.2	80.2
Carnegie—Illinois	79.3	79.9	....	....	....	80.4
Jones & Laughlin	79.3	80.0	80.2	80.3	....	80.3
Texas Co.	79.2	79.8	80.1	80.2	80.5	80.8
Sun Oil	79.2	80.0	80.3	80.3	80.4	80.5
Std. Oil Devel. Co.	79.5	79.9	80.2	80.4	80.5	80.7
Eastern Gas	79.3	79.8	80.1	80.2	....	80.4
Barrett	79.1	79.9	80.1	80.1	80.1	80.2
Minimum	78.5	79.8	80.0	80.1	80.1	80.2
Maximum	79.6	80.0	80.3	80.4	80.5	80.8
Average	79.25	79.88	80.11	80.19	80.30	80.42
METHOD 2—A.S.T.M. METHOD D 86 MODIFIED BY USE OF FLASK AND THERMOMETER SPECIFIED IN METHOD 1						
Shell (A)	....	....	....	....	....	....
Shell (B)	....	....	....	....	....	....
Std. Oil of Indiana	79.5	80.1	80.2	80.3	80.4	80.5
Carnegie—Illinois	79.1	79.8	....	....	....	80.4
Jones & Laughlin	79.3	79.9	80.2	80.2	....	80.4
Texas Co.	78.9	79.5	79.8	79.9	79.9	80.1
Sun Oil	79.2	80.0	80.3	80.3	80.4	80.5
Std. Oil Devel. Co.	79.4	80.0	80.2	80.3	80.4	80.9
Eastern Gas	79.4	80.0	80.2	80.4	80.6	80.6
Barrett	79.3	79.9	80.1	80.1	80.2	80.3
Minimum	78.9	79.5	79.8	79.9	79.9	80.1
Maximum	79.5	80.1	80.3	80.4	80.6	80.9
Average	79.26	79.90	80.14	80.21	80.32	80.48
METHOD 3—A.S.T.M. D 158 FLASK, A.S.T.M. D 86 CONDENSER AND RECEIVER, E I (40C-44T) and E I (41C-44T) THERMOMETERS						
Shell (A)	79.8	80.0	80.2	80.3	80.6	80.7
Shell (B)	79.7	80.0	80.2	80.3	80.4	80.7
Std. Oil of Indiana	79.6	80.0	80.3	80.3	80.4	80.5
Carnegie—Illinois	79.2	79.8	....	....	....	80.4
Jones & Laughlin	79.3	79.9	80.1	80.1	....	80.3
Std. Oil Devel. Co.	79.4	79.8	80.0	80.2	80.3	80.9
Barrett	79.0	79.8	80.1	80.1	80.2	80.2
Minimum	79.0	79.8	80.0	80.1	80.2	80.2
Maximum	79.8	80.0	80.3	80.3	80.6	80.9
Average	79.43	79.90	80.12	80.22	80.38	80.53

TABLE III.—DISTILLATION TESTS OF INDUSTRIAL GRADE TOLUENE.

	Temperature, deg. Cent.					
Distillation Points	Start	5 per cent	50 per cent	90 per cent	95 per cent	Dry Point
METHOD 1—PROPOSED TENTATIVE METHOD						
Shell (A)	109.9	110.0	110.5	110.7	110.7	110.9
Shell (B)	109.7	110.0	110.4	110.6	110.7	110.8
Std. Oil of Indiana	109.7	110.0	110.5	110.7	110.7	110.7
Carnegie—Illinois	110.0	110.5	....	....	....	111.4
Jones & Laughlin	109.5	110.1	110.6	110.8	....	110.8
Texas Co.	108.5	109.5	110.2	110.4	110.5	110.7
Sun Oil	109.1	109.7	110.2	110.4	110.5	110.6
Std. Oil Devel. Co.	108.4	109.9	110.4	110.6	110.6	110.6
Eastern Gas	109.5	110.2	110.7	110.9	....	111.0
Barrett	109.6	110.1	110.6	110.9	110.9	110.9
Minimum	108.4	109.5	110.2	110.4	110.5	110.6
Maximum	110.0	110.5	110.7	110.9	110.9	111.4
Average	109.39	110.00	110.49	110.63	110.66	110.84
METHOD 2—A.S.T.M. METHOD D 86, MODIFIED BY USE OF FLASK AND THERMOMETER SPECIFIED IN METHOD 1						
Shell (A)	....	....	....	....	....	....
Shell (B)	....	....	....	....	....	....
Std. Oil of Indiana	109.4	110.0	110.4	110.7	110.8	110.8
Carnegie—Illinois	109.8	110.5	....	....	....	111.4
Jones & Laughlin	109.5	110.1	110.5	110.7	....	110.8
Texas Co.	108.7	109.4	110.0	110.2	110.3	110.8
Sun Oil	109.0	109.8	110.3	110.5	110.5	110.6
Std. Oil Devel. Co.	108.2	109.6	110.1	110.4	110.4	110.4
Eastern Gas	109.4	110.1	110.6	110.8	110.9	111.0
Barrett	109.5	110.1	110.5	110.7	110.7	110.8
Minimum	108.2	109.4	110.0	110.2	110.3	110.4
Maximum	109.8	110.5	110.6	110.8	110.9	111.4
Average	109.19	109.95	110.34	110.57	110.60	110.83
METHOD 3—A.S.T.M. D 158 FLASK, A.S.T.M. D 86 CONDENSER AND RECEIVER, E I (40C-44T) and E I (41C-44T) THERMOMETERS						
Shell (A)	109.8	110.0	110.5	110.8	110.8	111.1
Shell (B)	109.7	110.0	110.5	110.7	110.7	111.
Std. Oil of Indiana	109.2	109.8	110.4	110.6	110.6	110.6
Carnegie—Illinois	110.0	110.4	....	....	....	111.3
Jones & Laughlin	109.2	109.8	110.3	110.5	....	110.6
Std. Oil Devel. Co.	....	....	....	....	....	....
Barrett	109.1	109.6	110.2	110.4	110.4	110.4
Minimum	109.1	109.6	110.2	110.4	110.4	110.4
Maximum	110.0	110.4	110.5	110.8	110.8	111.3
Average	109.50	109.93	110.39	110.60	110.63	110.83

TABLE IV.—DISTILLATION TESTS OF NITRATION GRADE TOLUENE.

Distillation Points	Temperature, deg. Cent.					
	Start	5 per cent	50 per cent	90 per cent	95 per cent	Dry Point
METHOD 1—PROPOSED TENTATIVE METHOD						
Shell (A)	110.4	110.5	110.6	110.7	110.7	110.8
Shell (B)	110.4	110.5	110.6	110.6	110.6	110.8
Std. Oil of Indiana	110.3	110.5	110.6	110.7	110.7	110.7
Carnegie—Illinois	110.6	111.1	......	......	......	111.2
Jones & Laughlin	110.3	110.6	110.7	110.8	......	110.9
Texas Co.	109.6	110.1	110.2	110.3	110.3	110.5
Sun Oil	109.8	110.2	110.3	110.4	110.4	110.5
Std. Oil Devel. Co.	110.0	110.2	110.4	110.5	110.5	110.6
Eastern Gas	110.2	110.5	110.7	110.7	......	110.8
Barrett	110.4	110.6	110.7	110.8	110.8	110.9
Minimum	109.6	110.2	110.2	110.3	110.3	110.5
Maximum	110.6	111.1	110.7	110.8	110.8	111.2
Average	110.20	110.48	110.53	110.61	110.57	110.77
METHOD 2—A.S.T.M. METHOD D 86, MODIFIED BY USE OF FLASK AND THERMOMETER SPECIFIED IN METHOD 1						
Shell (A)	......	......	......	......	......	......
Shell (B)	......	......	......	......	......	......
Std. Oil of Indiana	110.3	110.6	110.6	110.8	110.8	110.8
Carnegie—Illinois	110.6	111.0	......	......	......	111.2
Jones & Laughlin	110.2	110.6	110.7	110.7	......	110.8
Texas Co.	109.4	109.6	109.8	109.8	109.8	109.8
Sun Oil	109.9	110.3	110.4	110.5	110.5	110.6
Std. Oil Devel. Co.	110.0	110.6	110.6	110.8	110.8	111.0
Eastern Gas	110.3	110.6	110.8	110.9	110.9	111.0
Barrett	110.3	110.5	110.7	110.8	110.8	110.8
Minimum	109.4	109.6	109.8	109.8	109.8	109.8
Maximum	110.6	111.0	110.8	110.9	110.9	111.2
Average	110.13	110.48	110.51	110.61	110.60	110.75
METHOD 3—A.S.T.M. D 158 FLASK, A.S.T.M. D 86 CONDENSER AND RECEIVER, E I (40C-44T) AND E I (41C-44T) THERMOMETERS						
Shell (A)	110.4	110.6	110.7	110.8	110.8	110.9
Shell (B)	110.4	110.5	110.6	110.7	110.8	111.0
Std. Oil of Indiana	110.2	110.4	110.6	110.6	110.6	110.6
Carnegie—Illinois	110.6	110.9	......	......	......	111.2
Jones & Laughlin	110.1	110.3	110.5	110.6	......	110.6
Std. Oil Devel. Co.	110.0	110.5	110.6	110.8	110.8	111.0
Barrett	109.9	110.2	110.4	110.5	110.5	110.6
Minimum	109.9	110.2	110.4	110.5	110.5	110.6
Maximum	110.6	110.9	110.7	110.8	110.8	111.2
Average	110.24	110.49	110.57	110.66	110.70	110.84

TABLE V.—DISTILLATION TESTS OF INDUSTRIAL GRADE XYLENE.

	Temperature, deg. Cent.					
Distillation Points	Start	5 per cent	50 per cent	90 per cent	95 per cent	Dry Point
METHOD 1—PROPOSED TENTATIVE METHOD						
Shell (A)	134.3	135.5	139.1	144.5	148.3	>160.
Shell (B)	134.3	135.5	139.1	144.3	148.3	>160.
Std. Oil of Indiana	133.4	134.8	138.7	144.0	145.7	151.5
Carnegie—Illinois	133.3	135.5	139.2	...	...	152.3
Jones & Laughlin	133.1	135.1	138.7	143.5	...	152.3
Texas Co.	131.8	135.1	139.0	144.2	147.5	153.6
Sun Oil	133.4	134.9	139.0	144.1	147.8	153.5
Std. Oil Devel. Co.	133.2	135.0	139.2	144.2	147.5	152.9
Eastern Gas	131.4	133.0	138.9	144.0	...	150.3
Barrett	133.2	135.3	139.0	144.2	147.6	151.9
Minimum	131.4	133.0	138.7	143.5	145.7	150.3
Maximum	134.3	135.5	139.2	144.5	148.3	>160.0
Average	133.14	134.97	138.99	144.11	147.53	154.23
METHOD 2—A.S.T.M. METHOD D 86, MODIFIED BY USE OF FLASK AND THERMOMETER SPECIFIED IN METHOD 1						
Shell (A)	...	...	...	...	...	...
Shell (B)	...	...	...	...	...	...
Std. Oil of Indiana	132.7	135.1	138.8	143.7	146.5	152.2
Carnegie—Illinois	132.9	135.3	139.2	...	...	152.3
Jones & Laughlin	132.2	134.8	138.7	143.5	...	152.9
Texas Co.	132.4	135.0	138.8	143.7	146.9	152.8
Sun Oil	133.6	134.9	139.0	144.1	147.8	153.6
Std. Oil Devel. Co.	131.9	134.6	138.8	143.9	146.8	153.8
Eastern Gas	133.2	135.2	138.9	143.9	147.0	152.7
Barrett	132.8	135.3	139.1	143.7	146.0	151.7
Minimum	131.9	134.6	138.7	143.5	146.0	151.7
Maximum	133.6	135.3	139.2	144.1	147.8	153.8
Average	132.71	135.03	138.79	143.79	146.83	152.75
METHOD 3—A.S.T.M. D 158 FLASK, A.S.T.M. D 86 CONDENSER AND RECEIVER, E I (40C-44T) AND E I (41C-44T) THERMOMETERS						
Shell (A)	133.0	134.7	138.6	144.1	147.2	>152.0
Shell (B)	133.3	134.9	138.8	144.1	147.3	>152.0
Std. Oil of Indiana	132.4	134.6	139.0	143.9	146.9	151.0
Carnegie—Illinois	132.7	135.2	139.1	...	...	151.8
Jones & Laughlin	132.2	135.6	138.8	143.8	...	153.2
Std. Oil Devel. Co.	132.3	134.5	139.1	143.9	146.9	152.0
Barrett	131.5	134.8	138.7	144.0	146.6	151.7
Minimum	131.5	134.5	138.6	143.8	146.6	151.0
Maximum	133.3	135.6	139.1	144.1	147.3	153.2
Average	132.49	134.90	138.87	143.97	146.98	152.13

TABLE VI.—DISTILLATION TESTS OF NITRATION GRADE XYLENE

Distillation Points	Temperature, deg. Cent.					
	Start	5 per cent	50 per cent	90 per cent	95 per cent	Dry Point
Method 1—Proposed Tentative Method						
Shell (A)	139.1	139.2	139.6	140.1	140.4	141.6
Shell (B)	139.1	139.2	139.5	140.1	140.5	141.3
Std. Oil of Indiana	138.8	139.0	139.3	139.8	140.1	140.4
Carnegie—Illinois	139.1	139.6	...	...	...	141.2
Jones & Laughlin	138.9	139.1	139.4	139.9	...	140.5
Texas Co.	138.8	139.2	139.5	140.0	140.3	140.8
Sun Oil	138.6	139.1	139.4	140.0	140.4	141.0
Std. Oil Devel. Co.	138.9	139.2	139.6	140.2	140.5	141.0
Eastern Gas	139.0	139.4	139.6	140.2	140.6	140.9
Barrett	139.0	139.3	139.6	140.0	140.3	140.6
Minimum	138.6	139.0	139.3	139.8	140.1	140.4
Maximum	139.1	139.6	139.6	140.2	140.6	141.6
Average	138.93	139.23	139.50	140.03	140.39	140.93
Method 2—A.S.T.M. Method D 86, Modified by Use of Flask and Thermometer Specified in Method 1						
Shell (A)	...	...	...	...	...	...
Shell (B)	...	...	...	...	...	...
Std. Oil of Indiana	138.7	139.0	139.3	139.9	140.2	140.7
Carnegie—Illinois	139.1	139.6	...	...	...	141.2
Jones & Laughlin	138.6	138.9	139.3	139.7	...	140.4
Texas Co.	138.8	139.1	139.5	140.0	140.3	140.7
Sun Oil	138.8	139.2	139.5	140.0	140.4	141.0
Std. Oil Devel. Co.	138.4	139.0	139.4	140.0	140.2	140.8
Eastern Gas	138.9	139.3	139.7	140.2	140.5	140.9
Barrett	138.9	139.3	139.5	140.0	140.3	140.7
Minimum	138.4	138.9	139.3	139.7	140.2	140.4
Maximum	139.1	139.6	139.7	140.2	140.5	141.2
Average	138.78	139.18	139.46	139.94	140.32	140.80
Method 3—A.S.T.M. D 158 Flask, A.S.T.M. D 86 Condenser and Receiver, E I (40C-44T) and E I (41C-44T) Thermometers						
Shell (A)	139.0	139.2	139.6	140.2	140.5	141.0
Shell (B)	139.0	139.2	139.6	140.1	140.5	141.0
Std. Oil of Indiana	138.7	139.0	139.4	139.9	140.2	140.4
Carnegie—Illinois	138.8	139.3	...	...	...	141.0
Jones & Laughlin	138.7	139.1	139.4	139.9	...	140.5
Std. Oil Devel. Co.	138.1	139.0	139.4	140.0	140.2	142.0
Barrett	138.4	138.9	139.3	139.9	140.1	140.4
Minimum	138.1	138.9	139.3	139.9	140.1	140.4
Maximum	139.0	139.3	139.6	140.2	140.5	142.0
Average	138.66	139.10	139.45	140.00	140.30	140.90

TABLE VII.—DISTILLATION RESULTS CORRECTED TO UNIFORM TEMPERATURE AT 50 PER CENT OFF[a].

Material	Temperature for 50 per cent over	Method	Average Temperature, deg. Cent.				
			Start	5 per cent	90 per cent	95 per cent	Dry Point
Benzene, Industrial 90	84.2 C.	1	81.16	82.26	95.02	105.51	114.87
		2	80.95	82.25	94.73	105.18	114.96
		3	81.17	82.06	94.71	104.34	115.41
Benzene, Industrial Grade	80.1 C.	1	79.23	79.97	80.20	80.31	80.42
		2	79.24	79.87	80.17	80.28	80.43
		3	79.42	79.87	80.17	80.32	80.50
Toluene, Industrial Grade	110.6 C.	1	109.35	110.09	110.81	110.86	110.92
		2	109.36	110.13	110.83	110.88	111.00
		3	109.62	110.06	110.82	110.83	110.96
Toluene, Nitration Grade	110.6 C.	1	110.22	110.48	110.68	110.69	110.79
		2	110.14	110.49	110.70	110.72	110.77
		3	110.20	110.45	110.70	110.72	110.80
Xylene, Industrial Grade	139.0 C.	1	133.17	134.98	144.14	147.51	152.31[b]
		2	132.80	134.09	143.93	146.93	152.84
		3	132.62	134.89	144.12	147.25	152.24[b]
Xylene, Nitration Grade	139.6 C.	1	139.00	139.26	140.15	140.48	140.99
		2	138.87	139.24	140.11	140.42	140.87
		3	138.60	139.22	140.15	140.40	141.00

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[a] Includes all data received except those from one laboratory which did not give temperature at 50 per cent point.

[b] Widely discordant results from one laboratory for dry point omitted.

APPENDIX II

REPORT OF SPECIAL COMMITTEE ON AROMATIC PETROLEUM SOLVENTS

In July, 1944, a special committee consisting of W. H. Bahlke, chairman, W. L. Douthett, A. P. Hewlett, J. B. Hill, E. T. Scafe, and E. G. Travis was appointed to consider the desirability of formulating preliminary specifications for aromatic solvents from petroleum.

The concensus of the special committee is that the picture on production of aromatic solvents from petroleum has not developed sufficiently to warrant the proposal of even preliminary specifications for such materials.

There are only one or two refiners who currently produce aromatic type solvents. With so few producers, there is no immediate need for standardization. While there are other petroleum refiners who as a result of the impact of war are now producing aromatics for use in making explosives and aviation gasoline, it is felt that in general these refiners have been too much concerned with the production of those products to make definite plans for post-war utilization of the available equipment. Any attempt now to standardize would therefore be premature, and perhaps lead to undue commitments.

In conclusion it may be pointed out that in the event that Committee D-16 should choose to deal further with the question of aromatic solvents from petroleum there are some jurisdictional matters that seem to need attention. It appears that Committee D-1 on Paint, Varnish, Lacquer, and Related Products and possibly Committee D-2 on Petroleum Products and Lubricants, should be consulted to clarify the question of proper authorization or cooperation for development of specifications. Also, a better representation on Committee D-16 of refiners having aromatic producing equipment should be effected, since one half or more of such refiners are not now represented.

Respectfully submitted on behalf of the special committee,

W. H. Bahlke,
Chairman.

REPORT OF COMMITTEE D-17

ON

NAVAL STORES*

Committee D-17 on Naval Stores held only one meeting during the year, in connection with the Annual Meeting of the Society in New York, N. Y., on June 27, 1944. By-laws for the committee, which had been prepared and approved by the Advisory Committee, were adopted and distributed to all members of the committee. The membership has again increased, with a net gain of 4, bringing the total number of voting members up to 38.

Due to war-time conditions, it has not yet been possible to organize the Subcommittee on Rosin Oil. However, the chairman has been collecting information on the needs and value of standardized methods of test for rosin oil.

NEW TENTATIVES

The committee submits for publication as tentative[1] the following methods and definitions:

Methods of:

Test for Acid Number of Dark Colored Rosin (D 465 - 45 T),[2] proposed by Subcommittee IV. This method using the Clayton yellow test paper as an external indicator is intended for use in those cases where the color of a solution makes impossible the observation of an end point using an internal indicator,

Sampling and Testing Pine Tars and Pine Tar Oils,[2] proposed by Subcommittee VI, and

REVISION OF TENTATIVE

Definitions of:

Terms Relating to Naval Stores and Related Products (D 804 - 45 T)[3] proposed by Subcommittee IX.

ADOPTION OF TENTATIVE METHODS AS STANDARD

The committee recommends that the Tentative Methods of Sampling and Grading Rosin (D 509 - 44 T)[4] which were editorially revised and rewritten in 1944, after having been published as tentative since 1938, be approved for reference to letter ballot of the Society for adoption as standard, without revision. No adverse comments or suggestions for further revision have been received.

These recommendations have been submitted to letter ballot of the committee which consists of 39 voting members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVES			
Test for Acid Number of Dark Rosin (D 465 - 45 T)	21	0	5
Sampling and Testing Pine Tars and Pine Tar Oils	19	0	7
REVISION OF TENTATIVE			
Def. of Terms Relating to Naval Stores and Related Products (D 804 - 45 T)	25	0	1
II. ADOPTION OF TENTATIVE METHODS AS STANDARD			
Sampling and Grading Rosin (D 509 - 44 T)	24	0	1

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] See Editorial Note, p. 353.

[2] These methods were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[3] These revised definitions were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

[4] 1944 Book of A.S.T.M. Standards, Part II.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Softening Point of Rosin (J. M. Schantz, chairman).—The work of this subcommittee was interrupted to some extent by the resignation of its former chairman, C. E. Kinney. However, Mr. Kinney has continued to give attention to a project started several years ago, on the compilation of data on all known methods of determining melting point and softening point, which will be made available to the main committee for further consideration. This report should comprise a valuable contribution to the literature on the subject. As a result of this study, a modification of the A.S.T.M. Tentative Method of Test for Softening Point (Ball and Shouldered Ring Apparatus) (E 28 – 42 T),[4] in which the sample is heated in an air bath maintained at a selected constant temperature with relation to the expected softening point, has been tested in the laboratory of the chairman of the main committee. It is hoped that the results obtained with this modification will be available in published form at an early date for further consideration by Subcommittee I.

TABLE II.—ELECTROMETRIC TITRATION OF ROSIN SAMPLES.

Sample	Amount of Alkali to Change pH From 9.5 to 10.3, ml.	Increase in Acid Number Equivalent to Amount of Alkali Added
No. I	0.1	1.4
No. II	0.1	1.4
No. III	1.5	21.0
No. IV	0.5	7.0

Subcommittee IV on Acid and Saponification Number and Unsaponifiable Matter in Rosin (W. D. Pohle, chairman).—Due to increased urgent duties in connection with his regular work, the former chairman, C. C. Zeigler, asked to be relieved of the chairmanship. At Mr. Zeigler's suggestion his assistant, W. D. Pohle, was nominated as chairman of the subcommittee and elected at the 1944 Annual Meeting.

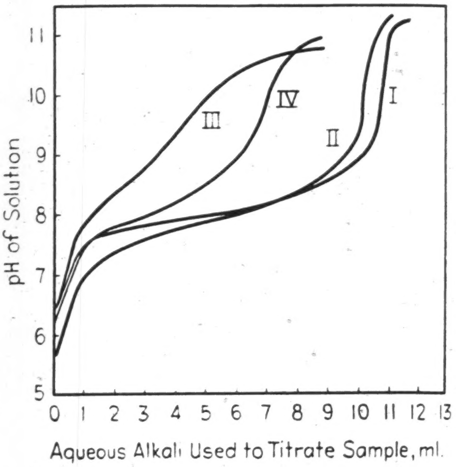

FIG. 1.—Titration Curves for Determining Acid Number of Rosin.

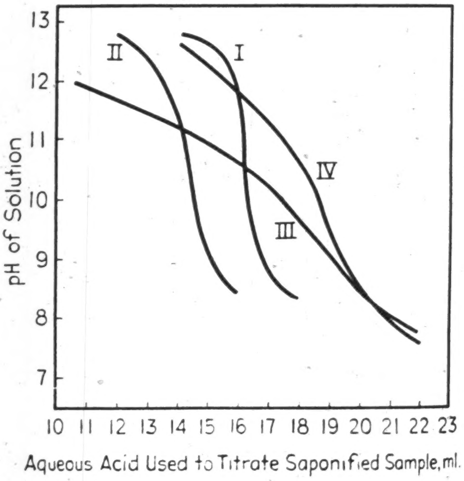

FIG. 2.—Titration Curves for Determining Saponification Number of Rosin.

A further study has been made of methods suitable for determining the acid number of dark rosins. Four samples were sent out to collaborating laboratories, two of ordinary pale grade rosin, and two of very dark resinous materials (Vinsol resin and Belro wood resin) having acid and saponification numbers considerably lower than the normal range for rosin. The color of the solution of these latter samples is so dark that the usual titration by a standard procedure using phenolphthalein as an internal indicator was extremely unreliable. In addition to a modification of the standard acid number test, the acid numbers were determined by electrometric titrations to prescribed pH values, and by a method using Clayton yellow paper as an external indicator. The results by electrometric titration gave unexpectedly widely varying acid number values. The subcommittee chairman thereupon made a further study of the problem and found that duplicate results can hardly be expected without some carefully controlled modification in the usual pH test procedures. The results of this supplementary investigation are shown in the accompanying Table II and Figs. 1 and 2. These results indicate that with rosins such as Samples Nos. III and IV, no sharp end point can be expected, and that greater variation must be permitted when analyzing such products than is customary for lighter colored rosins.

The procedure using Clayton yellow paper as an external indicator has long been used by one of the larger naval stores producers. While the results reported by several of the 1944 collaborators were not in good agreement, by eliminating the two to four highest and lowest results that were in marked disagreement with the rest of the figures, it was possible to obtain for the seven or eight remaining results an average value from which the individual figures used in computing such average do not deviate by more than a few units. In view of this, and in the light of our present knowledge of the titration characteristics of dark rosin, and having in mind that a special method is needed only when an accurate acidity titration with internal indicator is impossible, the subcommittee recommends the Method of Test for Acid Number of Dark Rosin[2] for publication as tentative at this time in the interest of the naval stores producing and using industries, since by such action it can more readily be given the additional study it requires. This new method is intended eventually for incorporation in the Standard Method of Test for Acid Number of Rosin (D 465 – 42).

While the correlation in the saponification number values for Samples Nos. III and IV using phenolphthalein test paper was fairly good, no recommendation for revising the Standard Method of Test for Saponification Number of Rosin (D 464 – 42) is being made, until further study of the proposed modification indicates its suitability for the purpose.

The results obtained on the study of the proposed method for unsaponifiable matter in rosin, in view of certain comments and recommendations made by several of the collaborators, indicate that this method should also be studied further before a recommendation is made that it be published as tentative.

Subcommittee V on Tall Oil (A. Pollak, chairman).—This subcommittee has conducted collaborative analyses on two samples of tall oil, in order to develop and perfect the Tentative Methods of Testing Tall Oil (D 803 – 44 T)[4] issued last year. Ten laboratories submitted their results. The concordance between different laboratories was not as good as had been expected, consequently no recommendation can be made at this time, pending further study of the results and comments submitted by the collaborating analysts. It is planned to send out additional samples for further study of these methods.

The Tentative Definitions of Terms Relating to Tall Oil (D 804 – 44 T) are recommended for incorporation in the more comprehensive definitions of terms relating to all naval stores products being recommended for publication as tentative this year.[1]

Subcommittee VI on Pine Tar and Tar Oil (J. P. Bain, chairman).—This subcommittee has made a study of various methods used by producers and consumers of pine tar for testing this material, from which the chairman has selected and compiled the methods which appeared most suitable. The subcommittee recommends that these Methods of Sampling and Testing Pine Tars and Pine Tar Oils[2] be accepted for publication as tentative, so that collaborative analysis of uniform samples may indicate what modifications or additions are needed. One of the most important tests on pine tar is viscosity, usually computed and reported in absolute viscosity units (centipoises), and determined with the Stormer viscosimeter. Many laboratories, however, do not have this instrument, but use the Saybolt viscosimeter. Since viscosities of tar are usually determined at either 30 or 50 C., depending on the type or grade, and since a basis for converting Saybolt Furol seconds to centipoises could be found only for 50 C., a study was made by a member of the subcommittee, on a number of tars, of the relationship between Saybolt Furol seconds and Stormer centipoises at both 30 and 50 C. From the results so obtained, a tentative alternate procedure and formula have been worked out and are included in the tentative methods, whereby Saybolt Furol viscosity can be converted to centipoises.

Subcommittee VII on Terpene Hydrocarbons and Pine Oil (I. E. Knapp, chairman).—A sample of dipentene and one of pine oil were sent out to members of the subcommittee for collaborative study of the Tentative Methods of Sampling and Testing Dipentene (D 801 – 44 T),[4] and of Pine Oil (D 802 – 44 T).[4] The variation in results, even on such simple tests as specific gravity and distillation was greater than would be expected. However, the deviations from the means for the various reported data were not so great as to indicate that the methods are not suitable. The subcommittee will make further collaborative tests during the coming year. It is hoped that closer study of the results will indicate what refinements or modifications in the methods are needed to bring about better agreement in results obtained by different collaborators.

The proposed revision of the Standard Methods of Sampling and Testing Turpentine (D 233 – 33) as prepared by this subcommittee and submitted to Committee D-1 on Paint, Varnish, Lacquer, and Related Products through its Subcommittee V was approved by that committee and accepted by Committee E-10 on Standards on October 30, 1944, for publication as Tentative Methods D 233 – 44 T.[4]

Subcommittee IX on Nomenclature and Definitions (J. L. Boyer, chairman).—This subcommittee has been quite active during the year and has compiled a comprehensive list of terms describing the various products of the naval stores industry, and many others related thereto. These definitions include the definitions relating to tall oil which were accepted for publication as tentative at the 1944 Annual Meeting. This list of Definitions of Terms Relating to Naval Stores and Related Products[3] is recommended as a revision of Definitions D 804 – 44 T. Any suggestions as to desirable additions or modifications in this list will be welcome.

This report has been submitted to letter ballot of the committee which consists of 39 voting members; 26 members returned their ballots, of whom 24 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

V. E. GROTLISCH,
Chairman.

W. A. KIRKLIN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-17 presented to the Administrative Committee on Standards two proposed new tentatives and revised tentative definitions, listed in the Summary of Proceedings, p. 10, and referred to in the report. These recommendations were accepted by the Standards Committee on August 1, 1945, and the new and revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

REPORT OF COMMITTEE D-18
ON
SOILS FOR ENGINEERING PURPOSES*

Committee D-18 on Soils for Engineering Purposes held one meeting during the past year, on June 27, 1944, in New York, N. Y. At that meeting Louis R. Douglass, Engineering Assistant to the Commissioner of the Bureau of Reclamation, was elected secretary of the committee, succeeding Wesley R. Nelson, resigned. The other officers were re-elected as follows: C. A. Hogentogler, chairman, and E. J. Kilcawley, vice-chairman.

On December 15, 1944, the Advisory Committee held a meeting in Washington, D. C., at which time Mr. Hogentogler stated that he had asked Prof. Kilcawley to serve as acting chairman. Mr. Douglass has been transferred from the Washington area, and Kenneth F. Vernon, Engineer in the Bureau of Reclamation, will serve as acting secretary. These officers will serve until the next regular election.

The Soil Testing Procedures, presented by the Symposium Committee and discussed at the Annual Meeting of the Society in June, 1943, were published as a separate publication in September 1944.

Subsequent to the 1944 Annual Meeting, Committee D-18 and Committee D-4 on Road and Paving Materials presented to the Society through Committee E-10 on Standards a proposed Tentative Method of Test for Determining Cement Content of Soil-Cement Mixtures. The new tentative method was accepted[1] by Committee E-10 on August 28, 1944, and appears in the 1944 Book of A.S.T.M. Standards, Part II, under the designation D 806 - 44 T.

I. NEW TENTATIVE

The committee has had under consideration for some time a Proposed Method of Test for Specific Gravity of Soils and, on the recommendation of Subcommittee IV, is submitting it for publication as tentative as appended hereto.[2]

This recommendation has been submitted to letter ballot of the committee which consists of 80 voting members; 58 members returned their ballots, of whom 53 have voted affirmatively, 3 negatively, and 2 members marked their ballots "not voting."

II. ADOPTION OF TENTATIVE AS STANDARD

On the recommendation of Subcommittee III, the committee recommends that the Tentative Methods of Surveying and Sampling Soils for Highway Subgrades (D 420 - 42 T)[3] be approved for reference to letter ballot of the Society for adoption as standard without revision.

This recommendation has been submitted to letter ballot of the committee which consists of 80 voting members;

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] In submitting this recommendation to Committee E-10 on Standards, Committee D-18 reported results of the letter ballot vote as follows: Of a total membership of 76, 50 members returned their ballots, of whom 35 voted affirmatively, 0 negatively, and 15 members marked their ballots "not voting."

[2] This method was accepted as tentative by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part II.

[3] 1944 Book of A.S.T.M. Standards, Part II.

56 members returned their ballots, of whom 55 have voted affirmatively, 0 negatively, and 1 member marked his ballot "not voting."

ACTIVITIES OF SUBCOMMITTEES

Several of the subcommittees report no activity because of war conditions.

Subcommittee IV on Methods of Testing the Physical Characteristics of Soils (Harold Allen, chairman).—As mentioned earlier in this report, the subcommittee has revised the Method of Test for Specific Gravity of Soils in the light of comments received and has again recommended it for publication[4] as tentative. The final draft of a new Method for Determination of Density of Soil in Place is now in preparation and will be submitted to letter ballot shortly.

Subcommittee VIII on Methods of Testing Soil Stability under Triaxial Shear Loading (R. F. Blanks, chairman).—At its meeting on December 15, 1944, the Advisory Committee approved a change in the title of Subcommittee VIII from "Methods of Testing for Mechanical Stability of Soils" to read "Methods of Testing Soil Stability under Triaxial Loading." At the same time, reorganization of the subcommittee to include only members having facilities and personnel for conducting research in triaxial shear testing was also approved.

Joint Subcommittee of Committees D-4 and D-18 on Tests and Specifications for Stabilized Soils (H. F. Clemmer, chairman).—A very satisfactory meeting of the joint subcommittee was held on March 19, 1945, with fourteen members and one visitor in attendance. Several of the sectional committee chairmen reported good progress on their assignments.

A letter ballot was taken in the joint subcommittee on the proposed adoption of the Tentative Method of Test for Moisture-Density Relations of Soils (D 698 - 42 T)[3] as standard, but in view of the negative viewpoints expressed, it was decided to continue this method as tentative pending consideration of the changes recommended.

This report has been submitted to letter ballot of the committee which consists of 80 voting members; 56 members returned their ballots, of whom 55 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

E. J. KILCAWLEY,
Acting Chairman.

K. F. VERNON,
Acting Secretary.

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[4] See Editorial Note, below.

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 10, the proposed Tentative Method of Test for Specific Gravity of Soils referred to in the report was submitted by Committee D-18 and accepted by the Administrative Committee on Standards on June 27, 1945. The new tentative appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

REPORT OF COMMITTEE D-19

ON

WATER FOR INDUSTRIAL USES*

Committee D-19 on Water for Industrial Uses and its subcommittees held meetings in New York, N. Y., on June 25, 26, and 27, 1944.

The committee sponsored a session on water at the 1944 Annual Meeting, June 27, 1944, in the form of a Round-Table Discussion on Organizing the Classification of Industrial Waters.[1]

A.S.T.M. Manual on Industrial Waters.—The outline of the Manual on Industrial Waters that is being sponsored by Committee D-19 as discussed in some detail in the 1944 report[2] is being developed in greater detail by the officers of the respective subcommittees responsible for specific chapters.

Reorganization of Subcommittees.—As indicated in last year's report[2] an expansion has been made in the organization of the various subcommittees of Committee D-19.

Section B on Resultant Deposits, of Subcommittee III on Methods of Sampling, has been discontinued and replaced by a new Section on Sampling of Water-formed Deposits and Corrosion Products which will give consideration to sampling methods for scale, sludge, corrosion products, and microbiological slimes. Section A on Analytical Methods and Section C on Special Methods of Subcommittee IV on Methods of Analysis are responsible for the preparation of methods of analysis. Subcommittee V on Classification has the responsibility of supplying definitions for the forms of deposits mentioned above and of preparing methods for reporting the results of analysis.

During the year the following subject subsections were organized: Subcommittee III on Methods of Sampling—Subject Subsection on Sampling of Water at Atmospheric Pressure (J. D. Yoder, chairman); Subcommittee IV on Methods of Analysis, Section A on Analytical Methods—Subject Subsection on Oil in Water (E. Bartow, chairman); Subcommittee V on Classification—Section B on Reporting Chemical Analysis of Water-formed Deposits and Corrosion Products (J. B. Romer, chairman).

The Society was represented by Max Hecht at a meeting of the Subcommittee on Care of Steam Boilers in Service, of the Boiler Code Committee, of The American Society of Mechanical Engineers, held in New York, N. Y., on June 25, 1944. This committee reviewed and edited proposed drafts of material presented by its members.

No meeting of the Executive Subcommittee of the Joint Research Committee on Boiler Feedwater Studies was held during 1944.

Subsequent to the 1944 Annual Meeting, Committee D-19 presented to the Society through Committee E-10 on Standards a proposed method for embrittlement testing of boiler water. This method was accepted by Committee E-10 for publication as tentative on

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 1051 (1944).

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 500 (1944).

August 28, 1944, and appears in the 1944 Book of A.S.T.M. Standards, Part III, under the title Tentative Method of Field Test for Tendency of Boiler Water to Cause Embrittlement Cracking of Steel (D 807 - 44 T)[3].

NEW TENTATIVE METHODS

The committee recommends that the new methods and recommended practice listed in Table I be accepted for publication as tentative, as appended hereto.[4, 5]

These recommendations have been submitted to letter ballot of the committee which consists of 71 members; 58 members returned their ballots with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
NEW TENTATIVE METHODS			
Test for Total Aluminum and Aluminum Ion in Industrial Waters	37	1	20
Test for Manganese in Industrial Waters	37	0	21
Test for Dissolved Oxygen in Industrial Waters[a]	31	4	23
Test for Silica in Industrial Waters	38½	½	19
Rec. Practice for Sampling Boiler Water from Stationary Boilers	33½	2½	22

[a] The classified vote on the Method of Test for Dissolved Oxygen in Industrial Waters was as follows: Affirmative: 11 producers, 8 consumers, 12 general interests; negative: 1 producer, 1 consumer, 2 general interests.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II, Editorial (E. P. Partridge, chairman).—According to the program previously developed, the preparation of methods with respect to form as well as to content is now carried out largely by members of the Editorial Subcommittee working with the various subject subsections of the other subcommittees. This procedure has been followed in the development of the methods being recommended for publication as tentative this year.

Subcommittee III on Methods of Sampling (D. K. French, chairman).—This subcommittee recommended for publication[5] as tentative the Recommended Practice for Sampling Boiler Water from Stationary Boilers[3] as developed by the Subject Subsection on Sampling of Stationary Boilers, of Section A of this subcommittee. This recommendation has been approved by letter ballot vote of the subcommittee as follows: From a membership of 42, 39 members returned their ballots, of whom 30 voted affirmatively, 3 negatively, and 6 members marked their ballots "not voting."

Progress is being made in the preparation of methods by other subject subsections of Section A. Section B on Sampling of Water-formed Deposits and Corrosion Products is receiving comments on a proposed procedure for sampling various forms of deposits.

Subcommittee IV on Methods of Analysis (A. A. Berk, chairman).—The subcommittee recommends for publication as tentative[4] the following methods, prepared by the subject subsections of Section A on Analytical Methods indicated:

Tentative Methods of Test for:

Total Aluminum and Aluminum Ion in Industrial Waters, prepared by the Subject Subsection on Iron, Aluminum, and Manganese,
Manganese in Industrial Waters, prepared by the Subject Subsection on Iron, Aluminum, and Manganese,
Dissolved Oxygen in Industrial Waters, prepared by the Subject Subsection on Dissolved Oxygen, and
Silica in Industrial Waters, prepared by the Subject Subsection on Silica.

These recommendations have been approved by letter ballot vote of the subcommittee which consists of 52 members as follows: Test for Aluminum, affirmative 27, negative 0, ballots marked "not voting" 9; Test for Manganese, affirmative 27, negative 2, ballots marked "not voting" 11; Test for Dissolved Oxygen, affirmative 31, negative 4, ballots marked "not voting" 23; Test for Silica, affirmative 27, negative 3, ballots marked "not voting" 3.

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[3] In submitting this recommendation to Committee E-10 on Standards, Committee D-19 reported results of the letter ballot vote as follows: Of a total membership of 70, 63 members returned their ballots, of whom 48 voted affirmatively, 1 negatively, and 14 members marked their ballots "not voting."

[4] The methods for determining aluminum, manganese, and silica and the recommended practice were accepted as tentative by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III. The method of test for dissolved oxygen in industrial waters was accepted by the Society for publication as information and appears in the appendix to this report, see p. 360.

See Editorial Note, p. 359.

The subcommittee has been reorganized to conform with the revised scope of Committee D-19. Section A on Chemical Methods, Section B on Electrometric Methods, and Section C on Special Methods are now functioning under the chairmanship of A. A. Berk, J. B. McIlroy and C. E. Imhoff, respectively.

The various subject subsections functioning under Section A on Analytical Methods have continued their program of activity. Some of these have not found methods available for development as referee procedures, hence they will contribute procedures of nonreferee character.

Section B on Electrometric Methods is continuing its survey of available methods.

Section C on Special Methods has, in addition to the development of methods, undertaken some work looking toward the classification of deposits. This section is studying the matter of reporting data and also has in preparation definitions applicable to each of the special methods. As it concerns the reporting of data, this subsection will coordinate its activities with those of Subcommittee V on Classification.

Subcommittee V on Classification (J. A. Holmes, chairman).—The work of the subcommittee on the various methods of classification of water has been somewhat clarified by the round-table discussion at the last annual meeting and through various committee meetings. The majority opinion seems to be that a more suitable and exact means of classification can be formulated for each industry or use of water than the simple comparison of typical analyses and that such an attempt should be made. This work may require two or three years before complete agreement on classification is reached for each industry.

The subcommittee has also submitted to its members preliminary drafts of definitions of various terms, such as alkalinity, hardness, deposits, scale, sludge, corrosion products, and slime.

These definitions are necessary so that analysts, engineers, and operators will agree on the common terms applied to the use of water.

A new section of the subcommittee was formed under the chairmanship of J. B. Romer, to prepare methods for reporting analysis of water-formed deposits and corrosion products. This work is well under way.

Subcommittee VI on Methods of Testing (V. V. Kendall, chairman).—This subcommittee prepared the Tentative Method of Field Test for Tendency of Boiler Water to Cause Embrittlement Cracking of Steel (D 807 – 44 T) which as mentioned earlier in this report, was accepted by Committee E-10 in August, 1944, for publication as tentative.

The Subsection on the National District Heating Association Corrosion Tester has prepared a Recommended Practice for Measuring Corrosion in Water Supplies—N.D.H.A. Method which is now under consideration in the subcommittee.

This report has been submitted to letter ballot of the committee which consists of 71 members; 58 members returned their ballots, of whom 42 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

MAX HECHT,
Chairman.

R. E. HALL,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-19 presented to the Administrative Committee on Standards the following recommendations:

Tentative Methods of Test for:
Total Aluminum and Aluminum Ion in Industrial Waters (D 857 - 45 T),
Manganese in Industrial Waters (D 858 - 45 T),
Silica in Industrial Waters (D 859 - 45 T), and
Tentative Recommended Practice for Sampling Boiler Water from Stationary Boilers (D 860 - 45 T).

The three methods and the recommended practice were accepted by the Standards Committee on August 27, 1945, and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III, bearing the designations indicated above.

At the same time, Methods of Test for Dissolved Oxygen in Industrial Waters were accepted by the Standards Committee for publication as information in the December, 1945, issue of the ASTM BULLETIN and in the Appendix to this Report on p. 360.

APPENDIX

PROPOSED METHODS OF TEST FOR DISSOLVED OXYGEN IN INDUSTRIAL WATERS[1,2]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. (*a*) These methods of test cover procedures for the determination of dissolved oxygen in industrial waters. Four methods are given, as follows:

	Sections
Referee Method	4 to 9
Non-Referee Method A	10 to 15
Non-Referee Method B	16 to 21
Non-Referee Method C	22 to 27

(*b*) The referee method covers the procedure for the most precise and accurate determination of dissolved oxygen in all industrial waters. Non-referee methods A, B, and C cover procedures of greater simplicity and lesser precision and accuracy than the referee method.

Sampling

2. Detailed requirements for sampling are given in the individual procedures. For general information on sampling, reference shall be made to the Standard Methods of Sampling Plant or Confined Waters for Industrial Uses (A.S.T.M. Designation: D 510).[3]

Purity of Reagents

3. Unless otherwise indicated, it is intended that all reagents shall be of the quality known as "reagent grade."

REFEREE METHOD

Application

4. This method is applicable to the most precise and accurate determination of dissolved oxygen in all industrial waters.

NOTE.—This method is particularly suited to the exact determination of concentrations less than 1 ppm. of dissolved oxygen. Where the water sampled contains more than 1 ppm. of dissolved oxygen, the high precision of this method may not be required.

Apparatus

5. The apparatus shall consist of the following:

(*a*) *Sample Tubes.*—Two glass sample tubes as shown in Fig. 1, having a nominal capacity of 500 ml. The two tubes should not differ from each other by more than 10 ml., and the capacity of each tube shall be determined to the nearest milliliter.

(*b*) *Burettes.*—Three 10- or 25-ml. burettes, having a stopcock bore not

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[1] These proposed methods are under the jurisdiction of the A.S.T.M. Committee D-19 on Water for Industrial Purposes.

[2] Published as information, August 27, 1945.

[3] 1944 Book of A.S.T.M. Standards, Part III.

greater than 1 mm. and a maximum tip diameter not exceeding 3 mm.

(*c*) *Beaker.*—An 800-ml. Griffin low-form beaker.

(*d*) *Stirrer.*—A variable-speed motor-driven stirrer with a glass propeller.

(*e*) *Calomel Electrode.*—Any calomel reference electrode of satisfactory size is suitable. A convenient form is a pencil type made of glass and provided with an external removable glass sleeve at the lower sealed end. This sleeve shall be slightly tapered, 1 to 2 cm. in length, and ground to fit so that the sealed end protrudes slightly beyond the sleeve. Midway of the ground section of the sealed tip there shall be two small, horizontal holes in register, providing an opening into the interior of the electrode. The electrode shall contain the necessary mercury, calomel, and electrical connection to the mercury and shall be nearly filled with a saturated (20 to 25 C.) solution of KCl, which solution can be replenished.

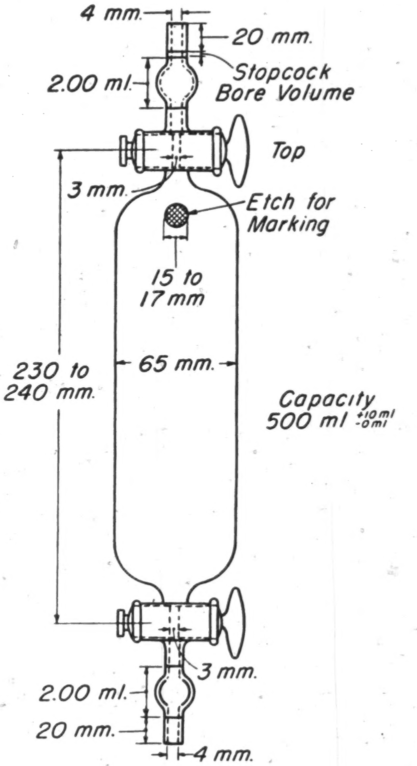

FIG. 1.—500-ml. Sample Tube for Dissolved Oxygen Determination.

(*f*) *Platinum Electrode.*—A length of capillary glass tubing, 12 to 13 cm. in length, with a short length of platinum wire or piece of platinum foil sealed through the lower end and making electrical contact with a column of mercury in the capillary.

(*g*) *Titration Stand.*—A suitable titration stand to support the stirrer and electrodes so that the beaker containing the sample can be removed easily, and permitting the rinsing of the electrodes and stirrer.

(*h*) *Pipettes.*—Serological pipettes of 1.00- and 5.00-ml. capacities, graduated in 0.01-ml. divisions.

(*i*) *Potentiometer.*—A potentiometer having a limit of error not greater than 0.0005 v. and a total range of the order of 1 v. is required. A galvanometer for use with this potentiometer, having an external critical damping resistance of the order of 10,000 ohms, shall be employed in order that current drained from the electrode system may be minimized by the use of an adjustable resistor. A galvanometer having a sensitivity of 0.125 microampere per millimeter division is desirable. The potentiometer may be of the type employing a self-contained galvanometer or of the type using an external galvanometer, as desired. A glass electrode pH meter may be used if equipped with the proper voltage range.

Reagents

6. (*a*) *Alkaline Potassium Iodide Solution.*—Dissolve 700 g. of KOH in sufficient distilled water to make approximately 700 ml. of solution in a 1-liter

volumetric flask and cool to room temperature. Dissolve 150 g. of iodate-free KI, in 200 ml. of distilled water and mix with the KOH solution in the volumetric flask. Dilute to 1 liter with water, mix, and store in a dark, rubber-stoppered bottle.

(*b*) *Iodine Solution* (*0.1 N*).—Dissolve 6.346 g. of resublimed iodine in a solution of 75 g. of KI in 60 ml. of distilled water and dilute with distilled water to 500 ml. in a volumetric flask. Store in a dark, stoppered bottle.

(*c*) *Iodized Alkaline Iodide Solution.*—Half fill a 250-ml. volumetric flask with the alkaline KI solution. Add an accurately measured, small amount of 0.1 *N* iodine (Note 1), sufficient to react with all reducing interference in the water to be analyzed when the procedure described below is followed. Dilute to the mark with the alkaline KI solution.

NOTE 1.—While the iodized alkaline iodide solution described in Paragraph (*c*) must be used for accurate determinations, the minimum sufficient quantity of 0.1 *N* iodine, as determined by trial, should be used because the precision of the results decreases with increase in iodine concentration. As a trial, use 10 ml. of 0.1 *N* iodine in preparing the iodized alkaline iodide solution and use on a test run. Prepare a second solution, if necessary, using more or less 0.1 *N* iodine, depending on the results of the test run.

(*d*) *Manganous Sulfate Solution.*—Weigh 480 g. of $MnSO_4 \cdot 4H_2O$ into a 600-ml. beaker. Add 200 ml. of distilled water, stir well, and transfer the supernatant solution to a 1-liter volumetric flask. Repeat three times, wash the last of the crystals into the flask, shake until solution is complete, and dilute to 1 liter with distilled water.

(*e*) *Sulfuric Acid Solution.*—Pour carefully 750 ml. of H_2SO_4 (sp. gr. 1.84) into 250 ml. of distilled water in a beaker. Cool to room temperature, transfer to a 1-liter volumetric flask, and dilute to the mark with distilled water.

(*f*) *Sodium Thiosulfate Solution* (*0.05 N*).—Dissolve 12.42 g. of $Na_2S_2O_3 \cdot 5H_2O$ in distilled water and dilute to 1 liter in a volumetric flask. Determine the exact normality by titration against a standardized solution of $K_2Cr_2O_7$ or $KH(IO_3)_2$ (Note 2).

NOTE 2.—If frequent restandardization of this solution is to be avoided, it must be stabilized with an inhibitor. One per cent of potassium furoate will limit the decrease in normality to less than 2 per cent in one year, over half of this decrease occurring in the first month. Four-tenths per cent of borax has been used for the same purpose.

(*g*) *Sodium Thiosulfate Solution* (*0.005 N*).—With a calibrated pipette, transfer 25.00 ml. of the 0.05 *N* $Na_2S_2O_3$ to a 250-ml. volumetric flask. Dilute to the mark with distilled water and mix completely. This solution shall be prepared not more than 12 to 15 hr. before using.

(*h*) *Starch Indicator Solution.*—Sprinkle 1 g. of soluble root starch into 100 ml. of boiling distilled water. Stir briefly, cool, and decant the clear, supernatant liquid. Prepare fresh daily.

Procedure

7. (*a*) *Sampling.*—Arrange the two sample tubes in a support so that they are vertical, and with their upper outlets at the same level. Connect the lower ends to the sampling line by means of rubber tubing and a Y-tube. The sampling line shall contain a suitable cooler if the water being sampled is above room temperature, in which case the sample shall be cooled to 60 to 65 F. (16 to 18 C.). If a cooler is used, the valve for cooling-water adjustment shall be at the inlet to the cooler and the overflow shall be to a point of lower elevation. The valve for sample-flow adjustment shall be at the outlet from the cooler. Adjust the sample flow to a rate which will fill the two tubes in 40 to 60 sec., and continue this flow long enough to provide

at least ten changes of water in the sampling tubes. If the sampling line is used intermittently, allow a suitably longer time for the first sample to insure adequate flushing of the sampling line and cooler. Close the upper stopcocks of the two tubes simultaneously (Note 1) and immediately close the two lower stopcocks and remove the tubing connections. Invert and examine both tubes to insure the absence of any gas bubbles. If any bubble is discovered, discard both samples and collect new ones.

NOTE 1.—If the line being sampled is under such high pressure that the sampling tubes or connecting tubing may burst with the water hammer when the stopcocks are closed, the sample flow may be throttled with the control valve just before the sample is removed, but the sample flow should not be shut off completely.

(*b*) *Fixing.*—Fill the three burettes with the iodized alkaline iodide solution, $MnSO_4$ solution, and H_2SO_4 solution respectively. Designate one of the duplicate tubes as the *sample* and the other as the *blank*. Refer to Fig. 1 to determine the upper stopcock of the sample flask. Flick the water from the upper nipple (Note 2) of the *sample* flask and fill the nipple to the upper calibration mark with the iodized alkaline iodide solution. Any bubble entrapped in the nipple within or below the reagent can be removed by probing with a clean copper wire until it rises to the surface. Open one stopcock and admit the reagent by control with the other until the meniscus in the nipple coincides with the lower calibration mark. Close both stopcocks and rinse both nipples of the sampling tube with a fine stream of water. Flick out the excess water, invert the tube, and fill the nipple now on top to the calibration mark with the $MnSO_4$ solution and introduce it into the sample as described for the addition of the iodized alkaline iodide solution. Again rinse both nipples of the sampling tube, shake or rotate the tube to mix the sample thoroughly, and lay it aside. Following precisely the directions given above for adding the reagents to the *sample*, add to the *blank* the indicated amount of iodized alkaline iodide solution through the upper nipple (Note 2) and stopcock, and add the same amount, first of H_2SO_4 solution and then of the $MnSO_4$ solution, through the lower nipple. Rinse both nipples between additions, as directed above, and mix the *blank* between the second and final addition. Finally, mix the *sample thoroughly*, as directed above, to resuspend the precipitate (Note 3). Add to the *sample* the indicated amount of H_2SO_4 solution, rinse both ends of the flask, and again mix thoroughly. Fixing should be completed within 15 min. after sampling.

NOTE 2.—The upper nipples of both tubes shall be used for the addition of the iodized alkaline iodide solution. The lower nipples shall be used for the $MnSO_4$ solution and the H_2SO_4 solution.

NOTE 3.—An error is introduced in the determination if the precipitate is allowed to settle so that more than a proportional amount is suspended in the volume withdrawn to permit the addition of the $MnSO_4$ solution.

(*c*) *Titration of Sample.*—Drain the sample into the clean 800-ml. beaker by opening both stopcocks. Do not rinse or blow through the sampling tube, but shake the last drops from the lower nipple into the beaker. Rinse both electrodes with distilled water, and readjust the sleeve on the calomel electrode to provide a fresh junction. Place the beaker on the titrating stand with both electrodes immersed in the sample, start the stirrer, and adjust its speed to mix the sample rapidly without causing a vortex sufficient to draw bubbles of air into the liquid. Read and record the emf. between the electrodes. Fill the 1- or 5-ml. pipette (Note 4), according to the volume required for the titration, with 0.005 *N* $Na_2S_2O_3$, and adjust exactly to the zero mark. Proceed with the titration, rinsing the tip of the pipette in the sample after each addition. Record the cumulative amount of thiosulfate and the emf. after each addition, and make progressively smaller additions as the end point is approached (Note 5) and passed. Titration should be completed within 30 min. after sampling. In a third column, parallel to those for milliliters of thiosulfate and emf., record the quotient $\frac{\Delta \text{ emf.}}{\Delta \text{ thiosulfate}}$ for each addition. The maximum numerical value of this quotient, without regard to sign, occurs at the end point of the titration. The end point can be identified by inspection of the values in the third column, so that plotting of the data is unnecessary.

NOTE 4.—A burette with 0.01-ml. divisions may be substituted for the pipette, but titrations can be made more rapidly with the pipette.

NOTE 5.—The addition of a few drops of starch indicator solution to the sample, developing the blue color of starch iodide, provides a convenient guide to the approach of the end point. Starch does not interfere with the determination, and the blue color disappears before the end point is reached.

(*d*) *Titration of Blank.*—Empty the beaker, rinse it and the electrodes with distilled water, prepare a fresh junction with the sleeve of the calomel electrode, and drain the blank into the beaker. Titrate the blank as described for the sample in Paragraph (*c*).

Calculation

8. Calculate the dissolved oxygen content of the sample, in terms of parts per million, by either the exact method or the rapid method, as follows:

Exact Method (*Note 1*):

$$I = \frac{2VN}{Cn}$$

$$D = \frac{6.5}{10{,}000n}$$

$$X = (S - (I + D)) \times \frac{8000n}{V_s}$$

$$Y = (B - I) \times \frac{8000n}{V_b}$$

$$\text{Dissolved oxygen, ppm.} = X - Y$$

Rapid Method (*Note 2*):

$$\text{Dissolved oxygen, ppm.} = \left(\frac{16{,}000n(S - B)}{V_s + V_b}\right) - 0.0104$$

where:

I = milliliters of $Na_2S_2O_3$ solution equivalent to the iodine introduced with the iodized alkaline iodide solution,

V = milliliters of iodine solution used in preparing the iodized alkaline iodide solution,

N = normality of the iodine solution (nominally 0.1),

C = capacity in milliliters of the flask used in preparing the iodized alkaline iodide solution,

n = normality of the $Na_2S_2O_3$ solution (nominally 0.005),

D = milliliters of $Na_2S_2O_3$ solution equivalent to the dissolved oxygen introduced with the fixing reagents (Note 3),

X = dissolved oxygen content of sample uncorrected for blank (Note 1),

S = milliliters of $Na_2S_2O_3$ solution required for titration of the sample,

V_s = volume of *sample* in milliliters,

Y = correction for blank (Note 1),

B = milliliters of $Na_2S_2O_3$ solution required for titration of the blank, and

V_b = volume of *blank* in milliliters.

NOTE 1.—With increase in reducing interference in the water sampled, first *Y* and then *X* becomes negative. If the algebraic instructions given in the formulas for calculation are followed, the calculated result will be correct.

NOTE 2.—Inaccuracy of the results calculated by the rapid method increases with difference in capacities of the two sampling tubes, the amount of oxygen dissolved in the water samples, and the concentration of redox impurities in the water. Unless these potential inaccuracies are known to be within the required limits of precision of the determination, the exact method of calculation should be used.

NOTE 3.—The factor *D* is derived from the determinations of Adams, Barnett, and Keller,[4] and of White, Leland, and Button,[5] which agree within less than 2 per cent. If there is any question of the validity of the factor *D* for the fixing solutions employed, the above references may be consulted for methods for determination of the appropriate value. In general, it will be found more economical to discard the questionable solutions and replace them with new solutions prepared from reagent-grade chemicals.

Precision and Accuracy

9. A skilled operator using this method can obtain results with a precision of 0.002 ppm. and with an accuracy of 0.003 ppm. or 1 per cent, whichever is the greater.

NON-REFEREE METHOD A

Application

10. This method is applicable to the determination of dissolved oxygen in all industrial waters, when the highest precision is not required.

Apparatus

11. The apparatus shall consist of the following:

(*a*) *Casserole.*—One 1-liter glazed porcelain casserole, clear white in color.

(*b*) *Miscellaneous.*—Sample tubes, burettes, and pipettes or burettes, as described in Section 5. The motor stirrer described in Section 5(*d*), if available, is of great convenience.

Reagents

12. For descriptions of the reagents required, see Section 6.

Procedure

13. (*a*) *Sampling.*—Collect the samples as described in Section 7(*a*), except that a cooling coil shall be provided if the water being sampled is warmer than 60 F. If the temperature of the cooling water is too high to attain this sample temperature, a supplementary cooler, such as a coiled length of copper tubing in a bath of cracked ice or ice water, shall be used. Do not attempt to cool the sample after collection.

(*b*) *Fixing.*—Fix the sample and blank as described in Section 7(*b*).

(*c*) *Titration of Sample.*—Drain the sample, which shall be at a temperature not above 70 F., into the clean casserole and add 10 drops of starch indicator solution. Fill the 1- or 5-ml. pipette, according to the volume required for the titration, with 0.005 *N* $Na_2S_2O_3$. Start the motor stirrer, if available, otherwise stir constantly with a clean glass rod. Titrate to the disappearance (Note) of the blue, starch iodide color, rinsing the tip of the pipette in the sample after each addition as the end point approaches.

NOTE.—Some analysts prefer to titrate to a faint trace of blue instead of to complete disappearance of the indicator color. Such results are subject to errors in misjudgment of color depth, but avoid the possibility of error by overrunning the end point. The two procedures are equally satisfactory for an experienced analyst.

(*d*) *Titration of Blank.*—Empty and rinse the casserole and drain the blank into it. Titrate as described in Paragraph (*c*).

Calculation

14. Calculate the dissolved oxygen content of the sample, in terms of parts per million, by the rapid method described in Section 8.

Precision and Accuracy

15. An experienced analyst using this method can obtain results with a precision of 0.004 ppm. and within 0.007 ppm.

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[4] R. C. Adams, R. E. Barnett, and D. E. Keller, Jr., "Field and Laboratory Determination of Dissolved Oxygen," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 1252 (1943).

[5] A. H. White, C. H. Leland, and D. W. Button, "Determination of Dissolved Oxygen in Boiler Feed Water," *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part II, p. 707 (1936).

or 1 per cent of the true value, whichever is the greater.

NON-REFEREE METHOD B

Application

16. This method is applicable to the determination of dissolved oxygen in industrial waters, when the highest precision is not required and the water is free of contamination (particularly, dissolved iron).

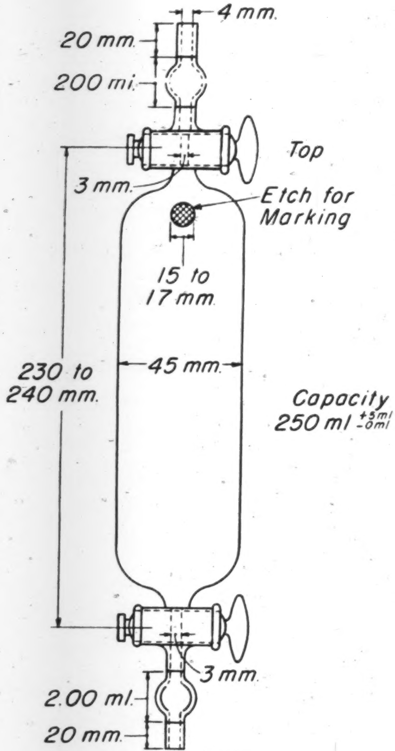

FIG. 2.—250-ml. Sample Tube for Dissolved Oxygen Determination.

Apparatus

17. The apparatus shall consist of the following:

(*a*) *Sample Tubes.*—One sample tube (Note) as shown in Fig. 1, having a nominal capacity of 500 ml. One sample tube (Note) as shown in Fig. 2, having a nominal capacity of 250 ml. The capacity of each tube must be determined to the nearest milliliter.

NOTE.—Four sample bottles as described in Section 23 (*a*) may be substituted for the preferred sample tubes if the latter are not available. In this case, three 1-ml. and three 2-ml. transfer pipettes must be provided for fixing. Resulting modifications of the procedure are given in Notes 1 to 3 in Section 19.

(*b*) *Graduate.*—One 500-ml. graduated cylinder.

(*c*) *Miscellaneous.*—Burettes, an 800-ml. beaker, and pipettes, as described in Section 5 (*b*), (*c*), and (*h*), respectively. A casserole as described in Section 11 (*a*).

Reagents

18. (*a*) For descriptions of reagents that are required, see Section 6 (*a*), (*b*), and (*d*) to (*h*).

(*b*) *Dilute Iodine Solution.*—Half-fill a 250-ml. volumetric flask with distilled water and dissolve in it approximately 50 g. of KI. Add 10 ml. of 0.1 *N* iodine, dilute to 250 ml. with distilled water, and mix thoroughly. Store in a stoppered dark bottle.

Procedure

19. (*a*) *Sampling.*—Collect the samples as described in Section 13 (*a*), using one 500-ml. and one 250-ml. sample tube (Note 1). Collect simultaneously a third portion of at least 250 ml. of the water being sampled. This may be done conveniently by arranging a clean 800-ml. beaker to catch the overflow from one or both of the sample tubes. The collected samples must be at a temperature not greater than 60 F. (16 C.) when removed from the sampling line.

NOTE 1.—When using sample *bottles* as described in Section 23 (*a*), provide four branches in the outlet from the sample cooler and collect the several samples simultaneously, as described in Section 25(*a*). When removing the individual samples, do not interrupt the flow through the remaining sample bottles.

(*b*) *Fixing.*—Fix both the 500-ml. and 250-ml. samples (Note 2) as *samples*, using 2.0 ml. each of alkaline potassium iodide solution (not iodized), $MnSO_4$ solution, and H_2SO_4 solution in that order as described in Section 7 (*b*).

NOTE 2.—When using sample *bottles*, fix the contents of two bottles with 1.0 ml. each of the three solutions and fix the contents of a third bottle with 2.0 ml. each of the three solutions following the procedure described in Section 25(*b*). Retain the contents of the fourth bottle as unfixed sample.

(*c*) *Titration.*—Drain the contents of the 500-ml. tube (Note 3) into the clean casserole and titrate with 0.005 *N* $Na_2S_2O_3$, as described in Section 13(*c*) (Note 4). Rinse the casserole with distilled water, and drain into it the 250-ml. sample (Note 3). Add to the casserole sufficient unfixed sample, collected as described in Paragraph (*a*) and measured in a graduated cylinder, to bring the contents to same volume as the contents of the 500-ml. sample tube and then titrate as described for the 500-ml. sample. Titration should be completed within 30 min. of sampling.

NOTE 3.—When using the sample *bottles*, combine the contents of the first two bottles (those fixed with 1 ml. of each solution) in the casserole and titrate the resulting 600-ml. sample. Similarly, combine the contents of the third bottle (that fixed with 2-ml. of each solution) and the fourth (unfixed) bottle and titrate as the second sample.

NOTE 4.—If the blue color of starch iodide does not develop when starch is added to one or both samples, discard both samples. To subsequent samples add an equal, small amount of iodine solution (Section 18(*b*)), measuring to an accuracy of plus or minus 0.01 ml. by use of a pipette (Section 5(*h*)). Carefully clean the pipette after using.

Calculation

20. Calculate the dissolved oxygen content of the sample, in terms of parts per million, as follows:

$$\text{Dissolved oxygen, ppm.} = \frac{8000n(S_1 - S_2)}{v_1 - v_2}$$

where:

n = normality of the $Na_2S_2O_3$ solution (nominally 0.005),

S = milliliters of $Na_2S_2O_3$ solution required for titration of the sample (Note),

v = fixed volume of sample in milliliters (Note).

NOTE.—Subscripts 1 and 2 refer to the larger and smaller samples respectively.

Precision and Accuracy

21. Where this method is applicable, an experienced analyst can obtain results with a precision of 0.004 ppm. and with an accuracy of 0.007 ppm. or 1 per cent, whichever is the greater.

NON-REFEREE METHOD C

Application

22. This method is applicable to the determination of dissolved oxygen in concentrations greater than 0.1 ppm., when high precision is not required. It is useful where rapid results are desired and is not suitable for the analysis of contaminated waters.

Apparatus

23. The apparatus shall consist of the following:

(*a*) *Sample Bottle.*—One 300-ml. B. O. D. bottle having a raised lip around the neck and a glass stopper ground to a conical lower tip. The capacity of the bottle must be measured to the nearest milliliter and the stopper should be tied to the neck of the bottle with a loop of cord.

NOTE.—A single sample tube (Section 5 (*a*)), is at least equally as satisfactory as the bottle.

(*b*) *Pipettes and Casserole.*—Three 2-ml. transfer pipettes, a casserole (Section 11(*a*)), and serological pipettes (Section 5(*h*)).

Reagents

24. For descriptions of the reagents required, see Section 6(*a*), (*d*) to (*f*), and (*h*).

Procedure

25. (*a*) *Sampling.*—Collect the sample as described in Section 13(*a*). Connect the source of the sample to a length of glass tubing slightly longer than the depth of the bottle. Put the glass tubing into the bottle and allow the bottle to fill and overflow, with the water entering at the bottom, until there have been at least ten changes of the contents. Wet the stopper and then slowly withdraw the glass tube while sample continues to flow through it. As soon as the tip of the tube clears the liquid surface, ease the stopper into the neck and let it float down into its seat. Twist the stopper in tight, invert the bottle, and inspect for air bubbles. If any can be seen, discard the sample and collect another.

(*b*) *Fixing.*—Fill a 2-ml. transfer pipette with alkaline potassium iodide solution (not iodized), and with the pipette filled to the tip so that no bubble of air will be forced into the sample, ease the bottle stopper out of its seat and simultaneously thrust the pipette tip past it and into the neck of the bottle. Allow the contents of the pipette to drain into the bottle and, as the level in the pipette approaches that in the bottle, raise the pipette out of the bottle and let the stopper fall back into its seat. Fill another 2-ml. pipette with $MnSO_4$ solution and add this to the sample in the same way. Seat the stopper tight, and shake or rotate the bottle to mix the contents thoroughly. Allow the bottle to stand and, when the precipitate has settled below the shoulder of the bottle, add 2 ml. of H_2SO_4 solution in the same way. Stopper and shake until all precipitate is dissolved. Fixing should be completed within 15 min. after sampling.

(*c*) *Titration.*—Empty the cup around the stopper of the bottle and wash it with distilled water. If the temperature of the sample is above 70 F., cool it by immersing the bottle in a bath of cracked ice. Remove the stopper, drain the contents of the bottle into the casserole, and titrate with 0.05 N $Na_2S_2O_3$ as described in Section 13 (*c*). Titration should be completed within 30 min. after sampling.

Calculation

26. Calculate the dissolved oxygen content of the sample, in terms of parts per million, as follows:

$$\text{Dissolved oxygen, ppm.} = \frac{8000nS}{v}$$

where:

n = normality of the $Na_2S_2O_3$ solution (nominally 0.05),
S = milliliters of $Na_2S_2O_3$ solution required for titration, and
v = milliliters of sample.

Precision and Accuracy

27. Where this method is applicable, an experienced analyst can obtain results with a precision of 0.03 ppm. and within 0.05 ppm. of the true values.

REPORT OF COMMITTEE D-20

ON

PLASTICS*

Since the June, 1944, meeting in New York, N. Y., Committee D-20 on Plastics and its subcommittees have held meetings in Atlantic City, N. J., in October, 1944, and in March, 1945. In addition, the Advisory Committee has held a joint meeting with the Advisory Committee of Committee D-9 on Electrical Insulating Materials in Philadelphia, Pa., in December, 1944.

A new Subcommittee X on Definitions, Nomenclature, and Significance of Tests has been organized under the chairmanship of G. W. Clark. Mr. Clark has also been appointed as the official representative of Committee D-20 on Committee E-8 on Nomenclature and Definitions, succeeding T. Smith Taylor. P. D. Brossman, has been appointed as the representative of Committee D-20 on Technical Committee XIII on Hydrogen Ion Determination, of Committee E-1. The Aircraft War Production Council has appointed F. P. Krieger and P. C. Silverstone to serve as its representatives on Committee D-20.

Subcommittee VIII on Research has been asked by Committee E-9 on Research to guide the A.S.T.M. representative in the work connected with the research project on plastics being carried on at the Massachusetts Institute of Technology under the sponsorship of the Plastics Materials Manufacturers' Association.

The scopes of subcommittees of Committee D-9 and Committee D-20 have been reviewed in an effort to minimize any duplication between the two committees. The work of Subcommittee VI relative to adhesives has been transferred to the recently organized Committee D-14 on Adhesives.

Subsequent to the 1944 Annual Meeting, Committee D-20 presented to the Society through Committee E-10 on Standards a number of recommendations which are listed in Table I, together with the results of the letter ballot vote in Committee D-20 and the date of acceptance by Committee E-10. The new and revised tentatives have been given the designations indicated and appear in the 1945 compilation of "A.S.T.M. Standards on Plastics" and in the 1944 Book of A.S.T.M. Standards.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is submitting one proposed new tentative method, revisions in five tentative specifications and methods of test, and is recommending the adoption of two tentatives as standard. These items are listed in Table II, and the recommendations are given in detail in Appendix I.[1]

The proposed tentative method covers an analytical procedure for ammonia.[2] There is a need for standardization of such analytical procedures. The committee therefore recommends the acceptance of this item. The proposed revisions of tentatives involve one specification, two test methods, the method of conditioning materials before and during testing, and a recommended practice for molding test specimens. The method of conditioning[3] is being somewhat simplified in regard to exposure requirements and additional standard temperatures are being added; the recommended molding practice is being extended to include an additional test specimen; additional limits are being added to the cellulose acetate sheet specification;[3] the light source is being more adequately specified in the haze method;[3] and details on the technique of machining the notch are being added to the impact method. The committee recommends the acceptance of all of these revisions.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] See p. 374.

[2] This method was accepted as tentative by the Society and appears in the 1945 Supplement to Book of A.S.T.M. Standards Part III.

TABLE I.—RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS, INCLUDING RECORD OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
New Tentative Specifications for:			
Cast Allyl Plastic Sheets, Rods, Tubes and Shapes (D 819-45 T), *accepted May 10, 1945*	26	0	43
New Tentative Methods of:			
Chemical Analysis for Acetyl and Butyryl in Cellulose Acetate Butyrate (D 817 - 44 T), *accepted December 11, 1944*	29	0	32
Test for Deformation of Plastics Under Load (D 621 - 44 T), *accepted December 13, 1944*, to replace Standard Method D 621 - 43	44	5	12
Test for Flow Properties of Thermoplastic Molding Materials (D 569 - 44 T), *accepted December 11, 1944*, to replace Standard Method D 569 - 43	35	1	25
Revision of Tentative Specifications for:			
Vinyl Chloride-Acetate Resin Sheets (D 708 - 44 T), *accepted August 28, 1944*	37	0	39
Vinyl Chloride-Acetate Molding Compounds (D 728 - 44 T), *accepted August 28, 1944*	35	0	41
Laminated Thermosetting Materials (D 709 - 44 T), *accepted August 28, 1944*	43	0	33
Revision of Tentative Methods of:			
Test for Resistance of Plastics to Accelerated Service Conditions (D 756 - 44 T), *accepted December 11, 1944*	38	1	22
Test for Heat Distortion Temperature of Plastics (D 648-44 T), *accepted May 10, 1945*	49	1	19
Test for Colorfastness of Plastics to Light (D 620 - 45 T), *accepted May 10, 1945*	38	1	30
Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 44 T), *accepted December 30, 1944*	39	6	16
Revision of Tentative Recommended Practice for:			
Molding Specimens of Phenolic Materials (D 796 - 44 T), *accepted December 22, 1944:*			
Mica-filled	31	2	28
Shock Resistant	32	2	27

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE			
Test for Determining Ammonia in Phenol-Formaldehyde Molded Materials	29	1	43
II. REVISION OF TENTATIVES			
Spec. for Cellulose Acetate Plastic Sheets (D 786 - 44 T) (1)	28	1	40
(2)	32	0	32
Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 - 43 T)	56	0	17
Test for Haze of Transparent Plastics by Photoelectric Cell (D 672 - 44 T)	44	0	20
Conditioning and Classifying for Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 44 T)	56	2	15
Rec. Practice for Molding Specimens of Phenolic Materials (D 796 - 44 T)	39	0	25
III. ADOPTION OF TENTATIVES AS STANDARD			
Descriptive Nomenclature of Objects Made From Plastics (D 675 - 43 T)	45	0	28

These recommendations have been submitted to letter ballot of the committee which consists of 127 voting members with the results shown in Table II.

ACTIVITIES OF SUBCOMMITTEES

All of the subcommittees have been very active during the past year. Much of the activity has concerned existing standards in an effort to make them more useful and more reliable. However, considerable work has been done on the development of new methods of test, analytical procedures, and specifications. This activity is being continued and a brief résumé of work now in progress follows.

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[3] These revised specifications and methods were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

Subcommittee I on Strength Properties (M. H. Bigelow, chairman).—A method for determining the tensile strength of thin film and foil has been developed and is being voted upon in the subcommittee. Work is being done on compression testing of long columns. The influence of the span-depth ratio on test results in flexural testing is under study. A revision of the Tentative Method of Flexural Test of Plastics (D 790 – 44 T), making it suitable for testing laminates, is ready for letter ballot in Committee D-20.

A round-robin test is being run on modifications of the falling ball impact method and on the reduced back-swing modification of the standard method. Considerable work on fatigue testing is in progress; the methods being evaluated are the rotating beam, the constant amplitude deflection, and the constant force deflection types. The Johnson shear method is being written up for submittal to letter ballot. Further work is being done on the bearing strength method. Other items being considered are methods for evaluating the strength properties of various types of laminates including the low-pressure, glass fiber types and the types consisting of combinations of high- and low-density materials. Also on the program are the problems of evaluating the bond strengths in laminates and a mandrel type flexibility test.

Subcommittee II on Hardness Properties (L. Boor, chairman).—Further studies are being made regarding the Rockwell hardness test in an effort to eliminate the differences between the A.S.T.M. Method D 785, Federal Method L-P-406, and Army-Navy Specification JAN-P-14. A revision is now being balloted upon in the subcommittee. Work on hardness testing is being continued; methods involving indentation, scratching, and falling abrasive are being studied. It is hoped that better methods of testing and evaluating can be achieved. A method of evaluating blocking resistance of flexible sheeting has been developed and will soon be submitted to letter ballot in Committee D-20.

Subcommittee III on Thermal Properties (W. A. Zinzow, chairman).—A method of test for determining cubical expansion has been submitted to letter ballot of the subcommittee.[4] A further revision of the method for determining deformation under load is also out to vote in the subcommittee.[4] Work is being continued on the study of flow properties by use of a parallel plate device. Other items under consideration are improvements in the heat distortion method and the development of a method for determining ignition temperature of plastics.

Subcommittee IV on Optical Properties (W. F. Bartoe, chairman).—Studies are being continued on methods of measuring haze and light transmission. Round-robin tests are in progress on methods involving use of the General Electric recording spectrophotometer and the use of an integrating sphere. Work is being continued on methods of test for measuring surface irregularities of plastics.

Subcommittee V on Permanence Properties (J. H. Teeple, chairman).—The standardization of procedures for operating carbon arc accelerated aging equipment is in process. Also under development is a method for determining the weight loss on heating. Work is being continued on moisture vapor permeability tests and on accelerated service tests.

Subcommittee VI on Specifications (G. M. Kline, chairman).—Specifications for polystyrene sheets, plates, rods, and tubes are being circulated for comment. The subcommittee is cooperating with the National Electrical Manufacturers Assn. in writing specifications covering post-forming laminating materials. A study is being made of the possibilities of combining the specifications for vinyl chloride and vinyl chloride acetate resins. A revision of the cellulose acetate sheet specifications concerning flammability of material under 20 mils in thickness has been submitted to letter ballot in the subcommittee. Revisions are also being considered in the specifications for ethyl cellulose molding compounds and for nonrigid vinyl chloride resins. The work on classification being done in cooperation with the Society of the Plastics Industry is being actively continued. A revision of the Tentative Specifications for Methacrylate Molding Compounds (D 788 - 44 T), involving reclassification and modification of several limits, is ready for letter ballot in Committee D-20.

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[4] See Editorial Note, p. 373.

Subcommittee VII on Analytical Properties (P. D. Brossman, chairman).—A method for determining insolubles in polystyrene is almost ready for reference to letter ballot in Committee D-20. A round-robin test is being run on a method for determining free phenol and free formaldehyde in phenol-formaldehyde resins. A tentative procedure has been prepared for the determination of plasticizer, residual solvent, pigment, and filler in cellulose ester plastics and is now being reviewed. A revision of A.S.T.M. Method D 115 on synthetic resin impregnants is being balloted upon by the subcommittee. The acetone extraction method for phenol formaldehyde resins is being reviewed.

Subcommittee VIII on Research (H. K. Nason, chairman).—Under active consideration are the problems of flow characteristics and impact strength. A formal program on impact testing has been set up. It is planned to examine the validity of the size and shape relationships demonstrated by Callender,[5] to study the relationship of the notch to the geometry of the present Izod impact test, and to study other methods of notching.

Subcommittee IX on Molds and Molding Processes (W. L. Hess, chairman).—Problems under active study are the effect of molding and mold design on physical properties, standardization of mold designs for test specimens, and standardization of molding technique. An encouraging start has been made but the problems are exceedingly difficult and a great deal of work must be done before much standardization can be accomplished.

Subcommittee X on Definitions, Nomenclature, and Significance of Tests (G. W. Clark, chairman).—Under consideration are a number of definitions including those for the terms "plastic," "thermosetting," "thermoplastic," etc. A standardized scheme for designation of flow of thermoplastic materials is being sent out to letter ballot in the subcommittee. Work is under way on developing for test specimens a standard system of designation which will indicate the direction of flow and the application of load during molding.

This report has been submitted to letter ballot of the committee which consists of 127 voting members; 73 members returned their ballots, of whom 64 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

ROBERT BURNS,
Chairman.

L. W. A. MEYER,
Secretary.

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[5] L. H. Callender, "New Methods for Testing Plastics," *British Plastics*, Vol. 13, No. 155, pp. 445-448 (1942); also Vol. 13, No. 156, pp. 506-519 (1942).

EDITORIAL NOTE

As indicated in the Summary of Proceedings, p. 11, recommendations affecting tentatives referred to in the report were submitted by Committee D-20 and accepted by the Administrative Committee on Standards on June 27, 1945. The new and revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

The proposed revisions in the Tentative Methods of Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 – 43 T) accepted subject to the concurrence of Committee D-9, as indicated in the Summary of Proceedings, p. 10, were not approved by Committee D-9 and accordingly these revisions were withheld pending further study.

Subsequent to the Annual Meeting, Committee D-20 presented to the Administrative Committee on Standards the following recommendations:

Revision of Tentative Method for:

Testing Deformation of Plastics Under Load (D 621 – 44 T).

New Tentative:

Method of Test for Coefficient of Cubical Expansion of Plastics (D 864 – 45 T).

These recommendations were accepted by the Standards Committee on December 10, 1945 and the new and the revised tentatives appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III, under the designations indicated above.

On December 10, 1945, the Standards Committee accepted the joint recommendation of Committee D-20 and Committee D-9 on Electrical Insulating Materials that the Tentative Specifications for Phenolic Molding Compounds (D 700 – 43 T) be revised. The revised tentative also appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

On January 17, 1946, the Standards Committee accepted the Tentative Method of Designating the Flow Temperature of Thermoplastic Molding Materials (D 863 – 45 T) which appears in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS ON PLASTICS

In this Appendix are given proposed revisions in certain tentative methods and specifications covering plastics which are referred to earlier in this report. These tentatives appear in their present form in the 1944 Book of A.S.T.M. Standards, Part III.

Tentative Methods of Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 – 43 T):[1]

Section 3 (*a*).—Change the second sentence of this paragraph to read as follows: "To insure the correct contour and condition of the specified notch, all specimens shall be notched as prescribed in Section 4."

Section 4.—Add a new section 4 to read as follows and renumber the subsequent sections accordingly:

4. *Notching Test Specimens:* (*a*) Notching shall be done with a milling cutter. Any standard milling machine or lathe, may be used. The cutting edge (Note 5) shall be carefully ground and honed so as to produce an angle between 44 and 46 deg. and a radius between 0.009 and 0.011 in. A 15 to 20 deg. negative rake is satisfactory.

NOTE 5.—Carboloy tips, or their equivalent, are strongly recommended, because of the importance of maintaining a sharp cutting edge. A supply of several cutters is advisable so that the notching equipment may be kept in use while dull cutters are being sharpened.

(*b*) The linear speed of the cutting tool shall not exceed 600 ft. per min. (Note 6).

(*c*) The feed shall be slow enough to result in a smooth cut. Speeds ranging from 0.5 to 5.0 in. per min. have proved satisfactory for some materials (Note 6).

NOTE 6.—While the speed ranges given in Paragraphs (*b*) and (*c*) have produced satisfactory notches in some plastic and electrical insulating materials, it may be necessary to study the effect of variation in these conditions when unfamiliar materials are to be notched.

(*d*) After cutting every 500 notches, or more frequently if hard abrasive materials are being notched, the cutter shall be inspected for sharpness, freedom from nicks, radius of tip and angle. If any signs of dullness are apparent, or if the angle and radius (Note 7) do not fall within their specified limits the cutter shall be replaced with one newly sharpened and honed. A microscope with a camera lucida attachment is suitable for checking the radius and angle.

NOTE 7.—Relatively close tolerances must be imposed upon the angle and radius of the notch because these factors largely determine the degree of stress concentration at the base of the notch during the test. The maintenance of a sharp, clean-edged cutting tool is particularly important, since minor defects at the base of the notch can cause large errors in test results.

Section 5.—Renumber Note 5 in this section as Note 8.

Section 8 (*a*).—Change the second sentence of this paragraph to read as follows: "To insure the correct contour and condition of the specified notch, all specimens shall be notched as prescribed in Section 4."

Tentative Method of Test for Haze of Transparent Plastics by Photoelectric Cell (D 672 – 44 T):

The revised specifications are appended hereto.[2]

Tentative Specifications for Cellulose Acetate Plastic Sheets (D 786 – 44 T):

The revised specifications are appended hereto.[2]

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[1] See Editorial Note, p. 373.

[2] These revised specifications were accepted by the Society and appear in the 1945 Supplement to Book of A.S.T.M. Standards, Part III.

Tentative Recommended Practice for Molding Specimens of Phenolic Materials (D 796–44 T):

Section 1.—Under "General Purpose Phenolic Materials" change "Impact test specimens 5 by ½ by ½ in." to read "Impact, flexural and tension test specimens."

Section 2.—Delete the present Paragraph (*a*) and substitute the following:

(*a*) *Molds:*

(1) For molding impact and flexure specimens of general purpose mica-filled and shock-resistant phenolic materials the single bar single cavity positive mold described in Fig. 2 of A.S.T.M. Specifications D 647 shall be used.

(2) For molding the tension specimens of general purpose, mica-filled and shock-resistant phenolic molding materials the positive mold shown in Fig. 4 of A.S.T.M. Specification D 647 shall be used.

Table I.—Change the heading under the caption "General Purpose Phenolic Materials" in the second column from "Impact Specimen 5 by ½ by ½ in." to read "Impact, Flexure, and Tension Specimens."

APPENDIX II

FLEXURAL PROPERTIES OF PLASTICS*

SUMMARY OF TEST RESULTS OBTAINED IN COMMITTEE D-20[1]

BY W. A. ZINZOW[2]

The object of this series of round-robin tests was to determine the effect of various factors on the flexural properties of plastics, prior to the preparation of the A.S.T.M. Tentative Method of Flexural Test of Plastics (D 790 - 44 T).[3] In 1941, Section F of Subcommittee I on Strength Properties of Committee D-20 on Plastics was organized with F. G. Tatnall as chairman of the section. The duty of the section was to present a proposed revision of the flexural strength methods which were in use for various types of plastics at that time. The methods that were in use at that time were those covered by A.S.T.M. Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 39)[4] and Tentative Methods of Testing Molded Materials Used for Electrical Insulation (D 48 - 41 T).[5] It was soon recognized that there were a large number of variables which might affect the results which would be obtained when following these testing procedures. Therefore, the section was organized to determine the effect of these various factors.

Five different laboratories cooperated in making these tests. They were as follows: Monsanto Chemical Co. Laboratory at Springfield, Mass.; Mechanical Engineering Laboratory at Rensselaer Polytechnic Institute; National Vulcanized Fibre Laboratory; Westinghouse Electric and Manufacturing Co. Laboratory; and the Bakelite Corp. Laboratory.

This section set out to determine the effect of the following factors on the flexural properties of the materials being tested. First, the effect of the loading edge radii; second, the effect of the rate of crosshead motion; third, the effect of the span-depth ratio.

From the mass of data reported by these laboratories covering these points an attempt is being made to abstract and present in a summary form some of the pertinent facts which were made available to this section. This is not intended to be a critical analysis of these data but is presented with the thought that members of the subcommittees in Committees D-9 on Electrical Insulating Materials and D-20 involved with these methods would be interested in the information upon which the writing of the Tentative Method D 790 was based.

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* Also published in A.S.T.M. BULLETIN, No. 134, May, 1945, p. 31.

[1] Submitted to Subcommittees II on Molded Insulating Materials and III on Plates, Tubes, and Rods of Committee D-9 on Electrical Insulating Materials and Subcommittee I on Strength Properties of Committee D-20 on Plastics by Section F of Subcommittee I of Committee D-20.

ED.—A continuation of the studies reported in this paper is given in a paper by E. M. Schoenborn, G. R. Proctor and Jaime Carvajal, "The Effect of Width and of Span—Depth Ratio on the Flexural Strength of Laminated Plastics." See p. 910.

[2] Chief Physicist, Bakelite Corp., Bloomfield, N. J.

[3] 1944 Book of A.S.T.M. Standards, Part III, p. 1634.

[4] 1939 Book of A.S.T.M. Standards, Part III, p. 265.

[5] 1941 Supplement, Book of A.S.T.M. Standards. Part III, p. 322.

EFFECT OF LOADING EDGE RADII

The tests to determine the effect of loading edge radii were made at the Monsanto Laboratories under the direction of H. K. Nason. The following quotation is taken from Nason's report covering this particular point.

"The effect of loading point radii on mechanical tests shows that the radius of the loading points has no measurable effect on the flexural strength or yield point of injection molded cellulose acetate or polystyrene. Figure 41 [accompanying Fig. 1.—ED.] shows that the variation from one experimental point to another is very similar for the two materials. The effect of loading edge radii by means of photoelastic tests up to a maximum fiber stress of approximately 3000 psi. no differences in the tensile stresses in the lower half of the bars could be detected, see Fig. 52 [accompanying Fig. 2.—ED.]. The fringe order was about one (in a total of 9) greater just below the $\frac{1}{64}$-in. radius molding point than for the 1-in. radius indicating a slightly higher stress concentration for the smaller radius. The difference is small, however, and it is believed that the variation in loading point radii over the range studied produces no serious change in stress distribution. A study of the four-point loading system gave essentially the same results as the three-point system."

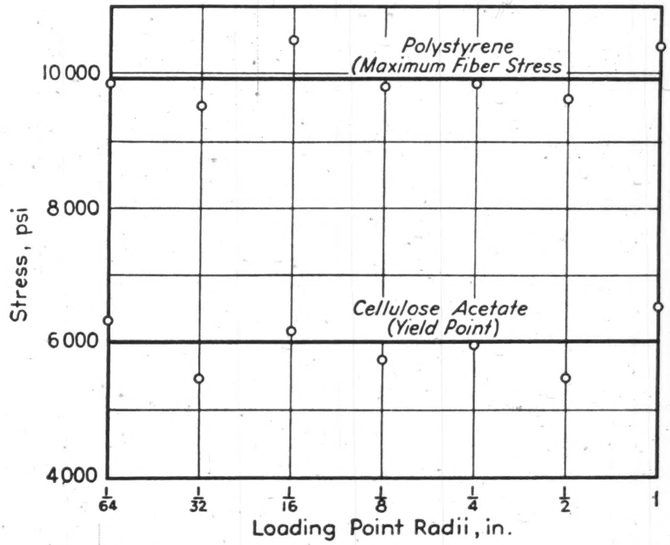
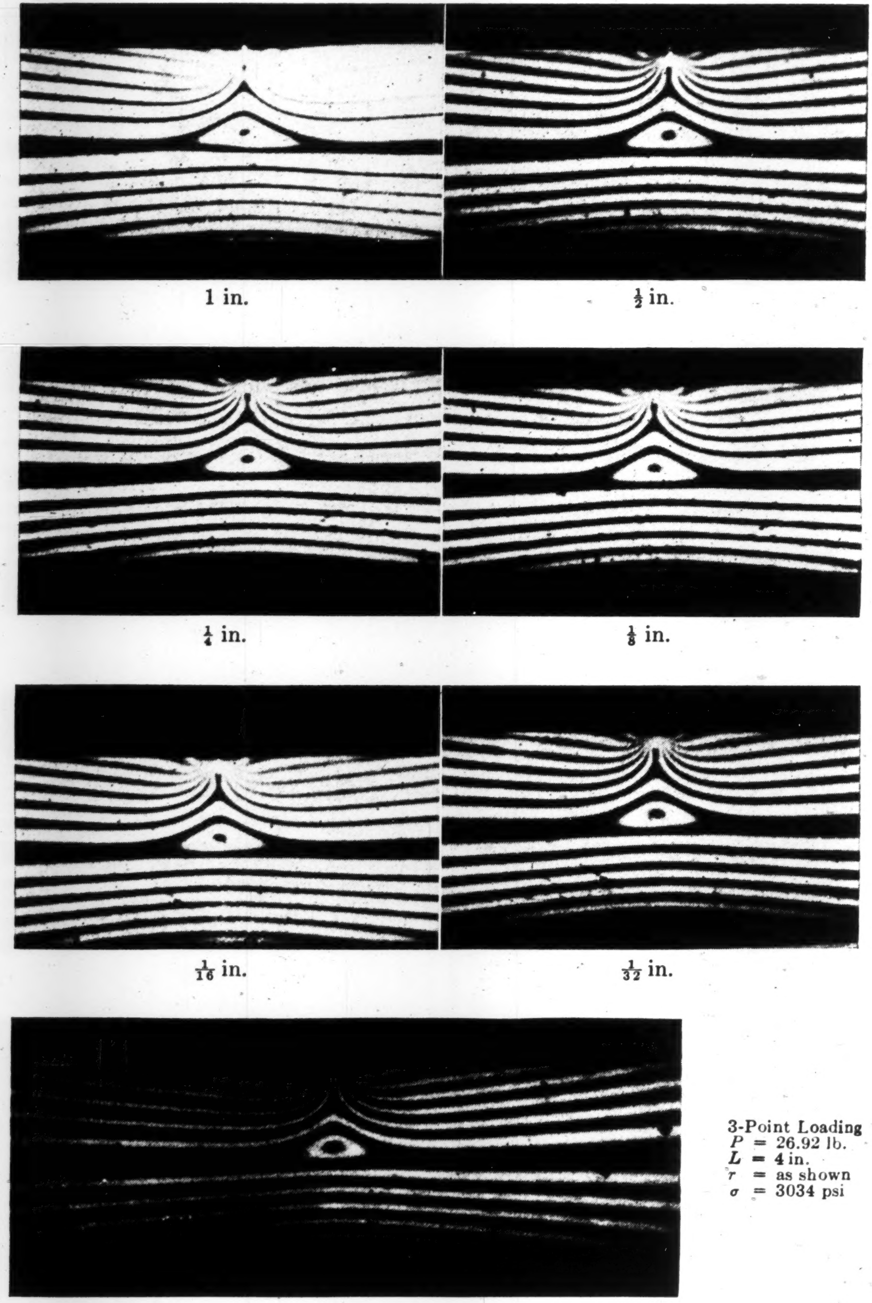


FIG. 1.—Flexural Strength *versus* Loading Point Radii.

From the above report it seems quite reasonable to assume that the radius of the loading edges has very little effect on the results obtained. However, the proposed test method calls for a definite radius of loading edge in order that this variable be eliminated as far as possible.



1 in.

$\frac{1}{2}$ in.

$\frac{1}{4}$ in.

$\frac{1}{8}$ in.

$\frac{1}{16}$ in.

$\frac{1}{32}$ in.

$\frac{1}{64}$ in.

3-Point Loading
P = 26.92 lb.
L = 4 in.
r = as shown
σ = 3034 psi

FIG 2.

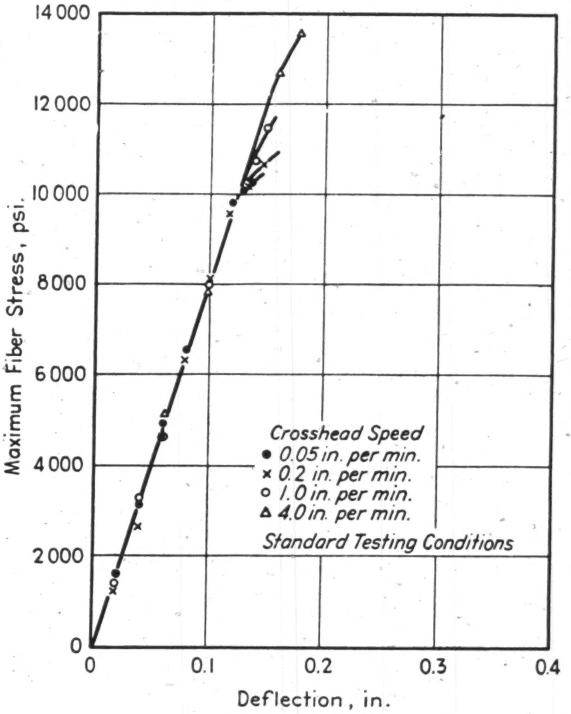


FIG. 3.—Effect of Speed on Flexural Stress Deflection Curves.

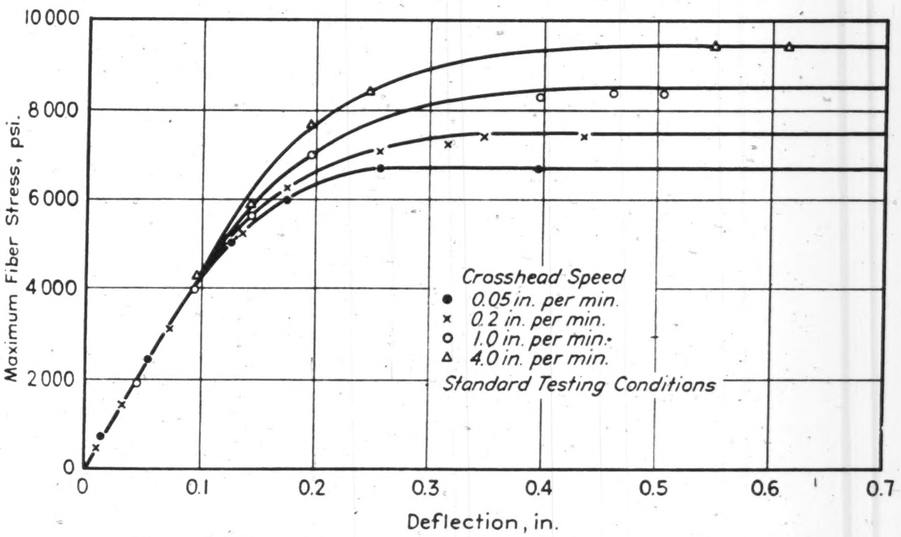


FIG. 4.—Effect of Speed on Flexural Stress Deflection Curves.

THE EFFECT OF RATE OF CROSSHEAD MOTION

The effect of the rate of crosshead motion or of the rate of loading on the modulus of rupture as well as the modulus of elasticity was covered by two different laboratories. Tests were made at Rensselaer Polytechnic Institute in the Mechanical Engineering Department under the direction of Leroy W. Clark. Similar work was carried out at the Monsanto Laboratories under the direction of H. K. Nason. Both laboratories reported the results of their test to the section. The results obtained at the Rensselaer Laboratories are shown by copies of curves submitted by Clark.

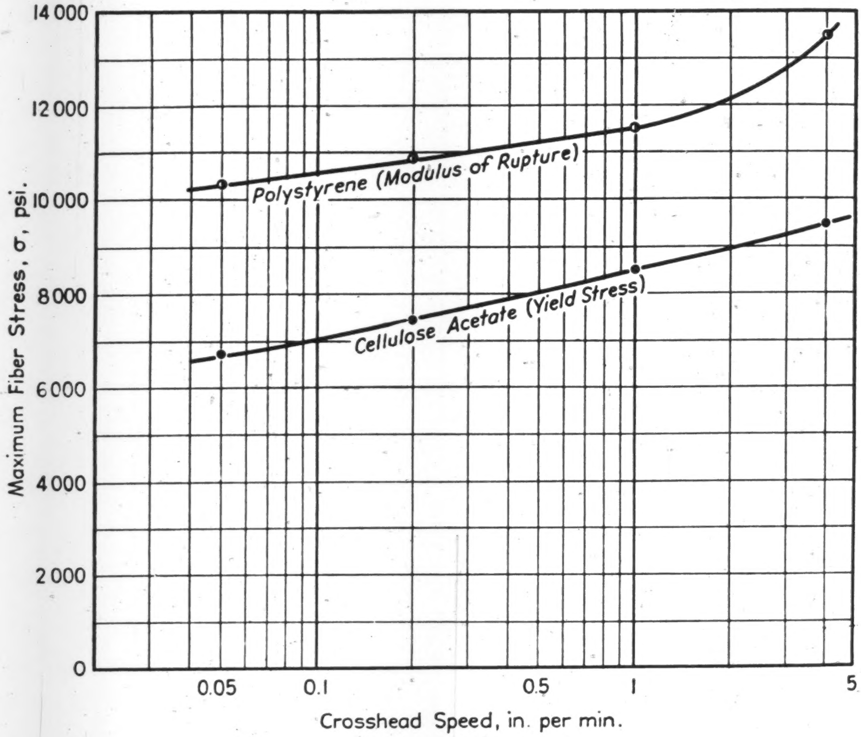


FIG. 5.

A summary of the Monsanto data is given in Figs. 3, 4, and 5 showing the effect of crosshead speed on the flexural stress deflection curves for both polystyrene and cellulose acetate. Figure 5 shows the effect of crosshead speed on the maximum fiber stress obtained for both of these materials.

The results of these tests seem to indicate that the ultimate modulus of rupture or the value of the maximum fiber stress for the more flexible materials is considerably affected by the effect of speed of crosshead motion. The data also show that the speed of testing does not produce any serious effect as far as could be determined for the modulus of elasticity measurements. As a result of these laboratories' data and

TABLE I.—RESULTS OF TESTS ON LAMINATED MATERIAL TESTED AT NATIONAL VULCANIZED FIBRE CO.

Material	Thickness, in.	Direction	Span-Depth Ratio	Strength, psi., avg.	Number of Tests	Deviation, per cent, avg.
Fibre	½	Lengthwise	8	21 200	6	1.6
			16	20 900	9	1.0
		Crosswise	8	17 900	10	1.7
			16	16 500	10	2.2
	¼	Lengthwise	8	25 800	10	2.4
			16	23 700	10	2.1
		Crosswise	8	18 300	10	1.7
			16	16 700	10	1.4
	⅛	Lengthwise	8	23 200	10	1.9
			16	19 800	9	4.7
		Crosswise	8	16 000	8	2.9
			16	13 200	10	4.9
	1/16	Lengthwise	8	30 000	9	1.9
			16	26 100	10	3.0
		Crosswise	8	19 800	9	1.0
			16	18 900	10	2.0
Phenolic XXX	½	Lengthwise	8	19 500	5	4.1
			16	19 200	5	2.5
		Crosswise	8	16 600	5	4.3
			16	15 200	5	2.1
	1/16	Lengthwise	8	27 800	4	2.1
			16	26 300	5	1.3
		Crosswise	8	20 400	4	0.7
			16	20 200	5	3.0
Phenolic C	½	Lengthwise	8	19 700	10	1.5
			16	17 600	7	2.2
		Crosswise	8	19 200	7	2.3
			16	18 100	9	1.5
	¼	Lengthwise	8	21 500	8	4.3
			16	19 700	10	2.8
		Crosswise	8	20 200	9	4.0
			16	20 000	10	1.4
	⅛	Lengthwise	8	22 700	10	3.4
			16	21 400	10	2.2
		Crosswise	8	22 900	10	3.4
			16	22 200	10	3.4
	1/16	Lengthwise	8	25 200	9	3.4
			16	23 600	9	2.6
		Crosswise	8	24 000	9	2.6
			16	22 400	10	2.7

considerable discussion at a series of section meetings, the section recommended that the rate of loading be such that a constant rate of straining be used. This rate of straining is approximately that obtained by the old standard methods used in D 48 and D 229 which called for a crosshead motion of 0.050 in. per min. when a ½ by ½-in. bar was tested using a 4-in. span between supports.

EFFECT OF SPAN-DEPTH RATIO

In all previous tests on flexural properties of plastics it was customary to use a span-depth ratio of 8 to 1. The experience of the plywood industry and the aircraft industry was such as to indicate that a larger span-depth ratio was desirable.

TABLE II.—RELATION BETWEEN THE ULTIMATE STRENGTH VALUES OBTAINED BY TWO SPAN-DEPTH RATIOS.

Material	Thickness, in.	Direction	Difference Between 16 to 1 Span Depth and 8 to 1 Span Depth
Fibre	½	Lengthwise	18.8
		Crosswise	16.8
	¼	Lengthwise	8.1
		Crosswise	8.7
	⅛	Lengthwise	14.6
		Crosswise	17.5
	1/16	Lengthwise	12.8
		Crosswise	4.5
Phenolic XXX	½	Lengthwise	16.2
		Crosswise	24.1
	1/16	Lengthwise	5.5
		Crosswise	8.0
Phenolic C	½	Lengthwise	10.6
		Crosswise	5.7
	¼	Lengthwise	8.4
		Crosswise	1.0
	⅛	Lengthwise	5.7
		Crosswise	11.8
	1/16	Lengthwise	6.3
		Crosswise	6.7

TABLE III.—RELATION BETWEEN MODULI OF ELASTICITY OBTAINED BY TWO SPAN-DEPTH RATIOS.

Material	Thickness, in.	Direction	Modulus of Elasticity		
			For 16 to 1 Span Depth, psi.	For 8 to 1 Span Depth, psi.	Difference, per cent
Fibre	½	Lengthwise	1 330 000	1 060 000	25.4
		Crosswise	820 000	853 000	3.9
	¼	Lengthwise	1 230 000	1 030 000	19.4
		Crosswise	830 000	744 000	11.6
	⅛	Lengthwise	625 000	745 000	6.7
		Crosswise	520 000	510 000	2.0
Phenolic XXX	½	Lengthwise	1 400 000	1 300 000	7.7
		Crosswise	1 190 000	1 170 000	1.7
Phenolic C	½	Lengthwise	1 090 000	1 200 000	9.2
		Crosswise	1 060 000	1 113 000	4.9
	¼	Lengthwise	1 080 000	950 000	13.7
		Crosswise	1 030 000	990 000	4.0
	⅛	Lengthwise	1 280 000	803 000	59.5
		Crosswise	860 000	850 000	1.2

The tests on all thicknesses of the materials except the 116 in., were made on a Tinius Olsen 50,000-lb. capacity motor-driven Manual Balancing Testing Machine with deflections determined by the use of an Ames gage reading to 0.0001 in. mounted on the crosshead of the machine. Adjustments were made for the maximum load of 5000 lb., and under such an adjustment this machine can read loads to the nearest one pound. The 116-in. thick material could not be satisfactorily tested on the above-mentioned equipment and was tested on a Steel City Testing Machine of the Hydrualic Type of 3500-lb. capacity, adjusted for a maximum load of 350 lb. With this adjustment the machine is capable of reading ½-lb. loads.

Therefore, the section determined to investigate the subject as extensively as possible. Tests were made in three different laboratories on different types of materials.

The results obtained at the National Vulcanized Fibre Laboratories are summarized in Tables I, II, and III.

The results obtained at the Westinghouse Laboratories are shown in Figs. 6 to 8.

The results obtained at the Bakelite Laboratories are also shown in Figs. 9 to 14.

The results shown by these data are not clear cut in all respects. However, generally it is possible to draw these conclusions. The modulus of rupture obtained seems to vary some with the span-depth ratio. Generally the modulus of rupture as calculated by the conventional relationship decreases slightly as the span-depth ratio increases. The results, however, do indicate that the rate of change of this value with flexural strength seems to be decreasing somewhat at span-depth ratios above 12. Since most of these test results were obtained by use of a constant rate of crosshead motion the rate of straining applied to the longer test specimens would be lower. This might result in somewhat lower modulus of rupture values as shown by Clark's and Nason's results.

The results of the tests at the National Vulcanized Fibre Laboratories do not indicate that greater consistency in test results would be obtained by either method.

Theory in the field of mechanical engineering indicates that the 8 to 1 span-depth ratio throws this testing into what is usually called the short beam test in which case there seems to be considerable possibility of introducing error due to shear stresses during the testing procedure. Generally, mechanical engineers favor the longer beam or longer span-depth ratio for that reason.

The results of the tests in these three laboratories also indicate that generally the modulus of elasticity as calculated by the conventional deflection equation increases somewhat

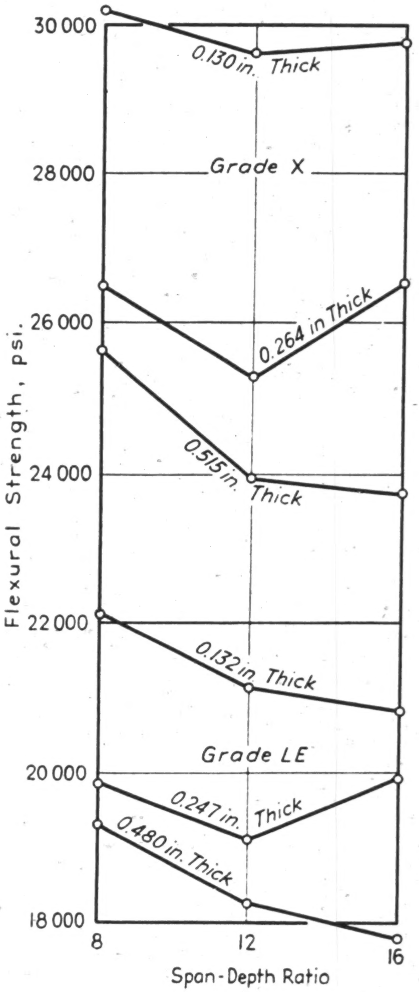


FIG. 6.

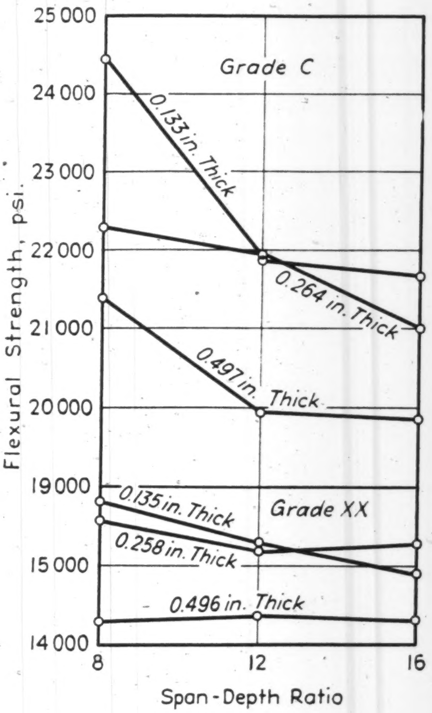
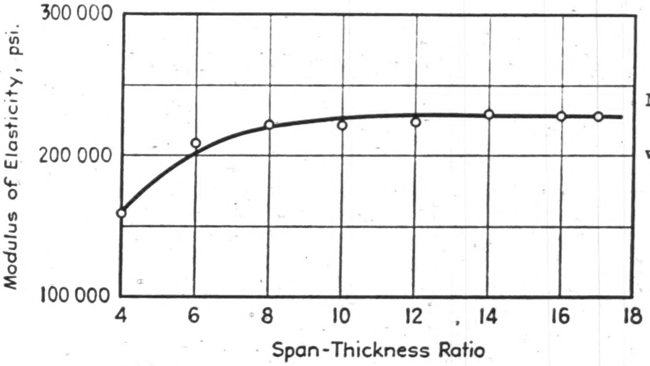


FIG. 7.



Modulus of Elasticity $M = \frac{PL^3}{4bd^3l}$

where: L = span width,
P = load producing,
l = deflection,
d = thickness, and
b = width.

FIG. 8.—Effect of Span Width-Thickness Ratio on Apparent Modulus of Elasticity By Flexural Test of Injection Molded Cellulose Acetate. Test Specimens $\frac{1}{4}$ by $\frac{1}{2}$ by 5-in.

for the longer span-depth ratios. The reason for this may be the result of two things: One, the fact that the conventional deflection equation is based on the assumption that the effect of shear stresses is negligible, and, second, that the popular technique of measuring deflections may

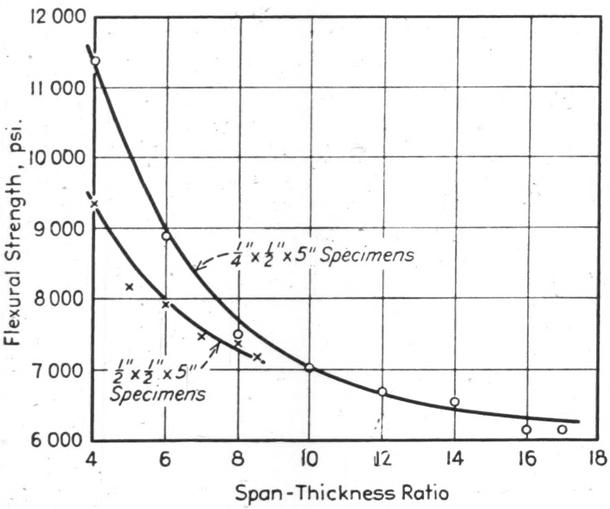


FIG. 9.—Effect of Span Width-Thickness Ratio on Flexural Strength of Injection Molded Cellulose Acetate.

Flexural Strength $= \frac{3PL}{2bd^2}$

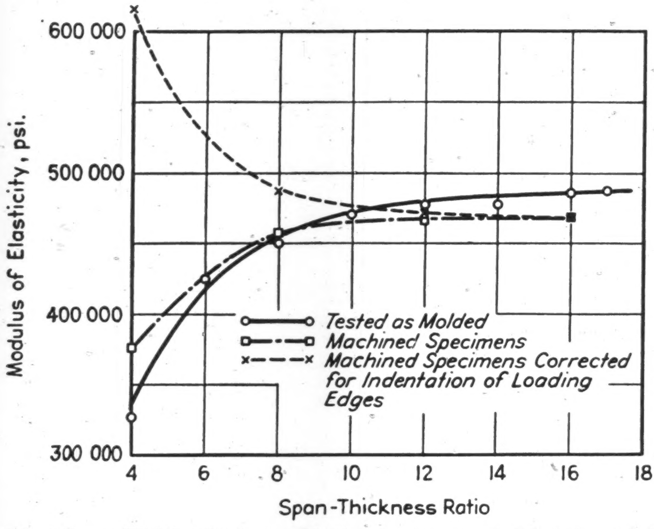


FIG. 10.—Effect of Span Width-Thickness Ratio on Apparent Modulus of Elasticity by Flexure Test of Injection Molded Styron. Test Specimens $\frac{1}{4}$ by $\frac{1}{2}$ by 5-in.

Modulus of Elasticity $M = \frac{PL^3}{4bd^3l}$

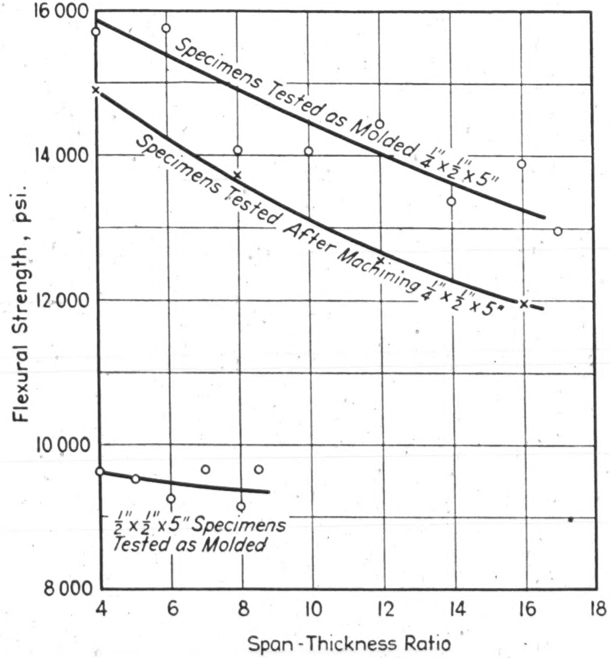


FIG. 11.—Effect of Span Width-Thickness Ratio on Flexural Strength of Injection Molded Styron.

$$\text{Flexural Strength} = \frac{3PL}{2bd^2}$$

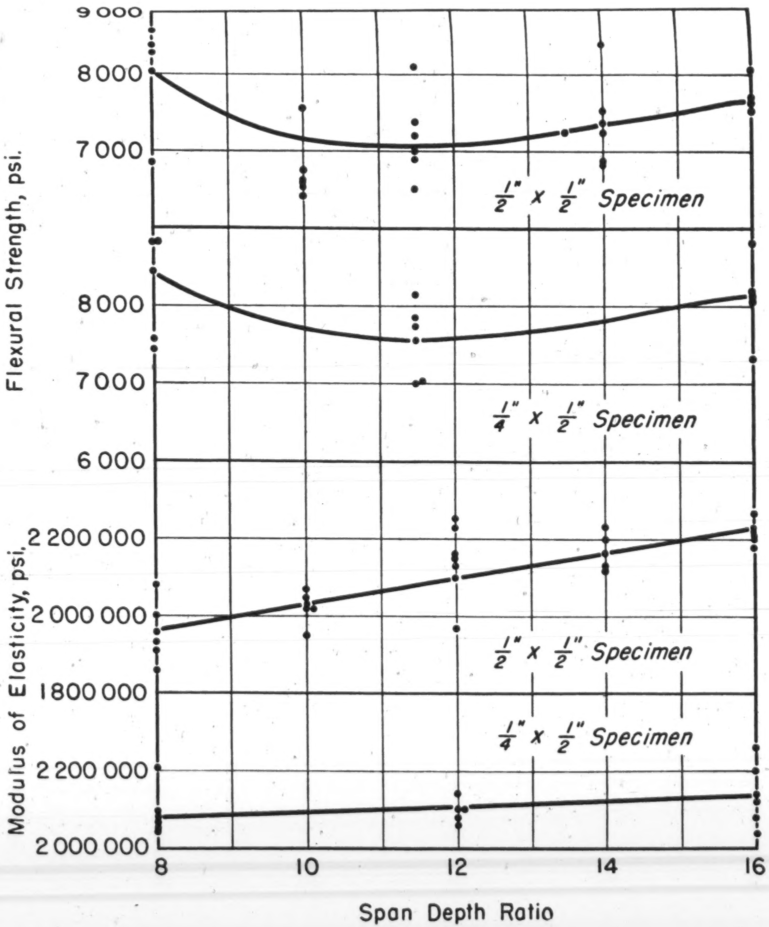


FIG. 12.—Effect of Span-Depth Ratio on Flexural Strength and Modulus of Elasticity of BM-021.

introduce an error because of the indentation of loading edges.

When the simple beam method of test is used with the load applied at the midspan line a correction in the measured deflection should be made because the shear deflection introduced by the low span-depth ratio is not negligible. The observed deflection is too large by a factor depending on the geometry of the test specimen and the location of the loading edges. For a $\frac{1}{2}$ by $\frac{1}{2}$-in. bar tested on 4-in. span supports this correction factor for the deflection is approximately 5 per cent. For a $\frac{1}{2}$ by $\frac{1}{2}$-in. bar tested on 8-in. span supports this correction factor is of the order of 1 per cent. This correction should be applied to observed values of the deflection produced by a given applied increment of load. The result of such a correction would be a higher modulus of elasticity than was actually calculated using always the simplified beam formula.

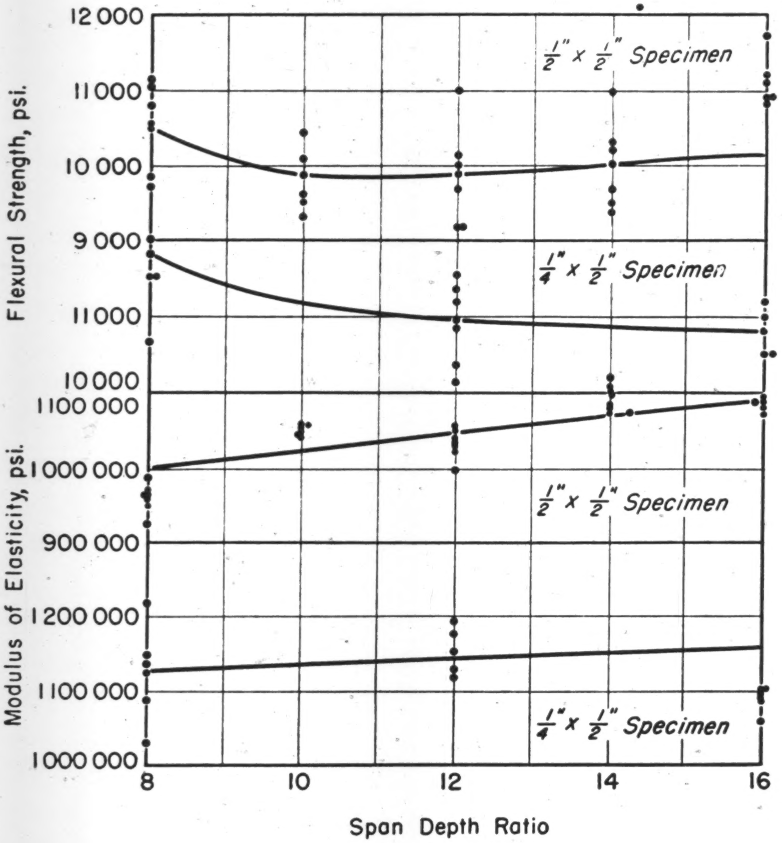


FIG. 13.—Effect of Span-Depth Ratio on Flexural Strength and Modulus of Elasticity of BM-261.

Another error frequently found in measurements of modulus of elasticity is the error in the apparent deflection caused by the indentation of the loading edges. For soft materials, such as plastics, the loading edges make an indentation in the specimen. If the deflection of the test bar is measured, as it frequently is, with a dial gage micrometer the measurement made is usually the relative motion of the two sets of loading edges. Sometimes the deflection of the midpoint of the bar relative to the supporting edges is used. Any indentation of the supporting or loading edges would then tend to give an apparent deflection reading for the test specimen which is too high by the amount of this indentation. For example, it was

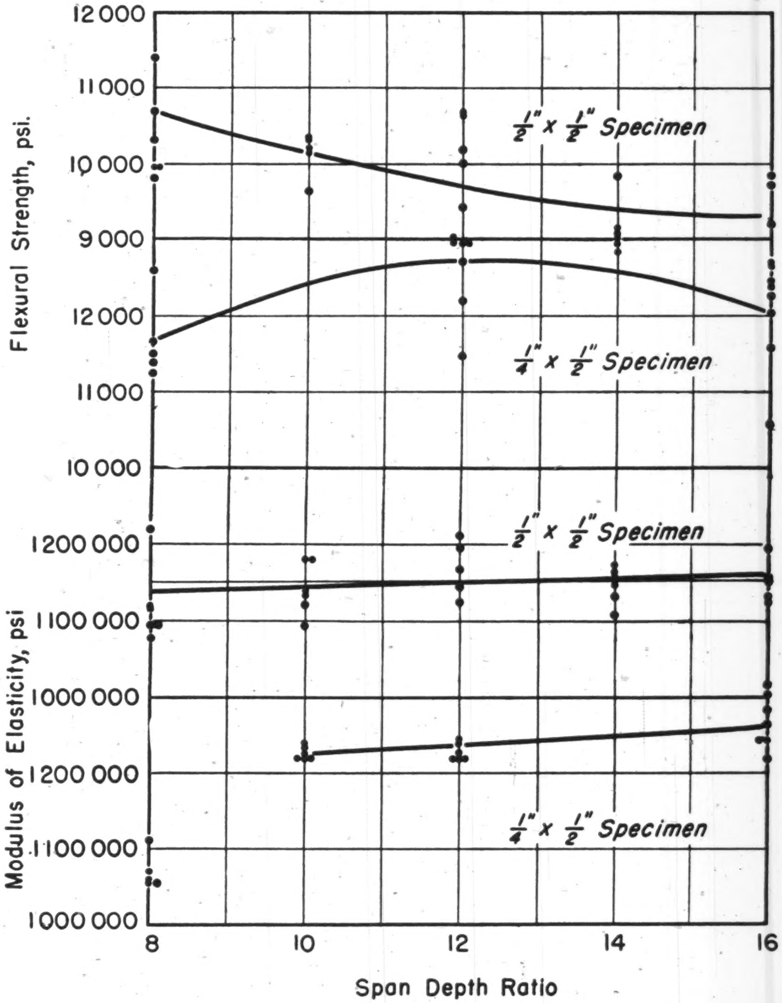


FIG. 14.—Effect of Span-Depth Ratio on Flexural Strength and Modulus of Elasticity of BM-3510.

found in the Bakelite Laboratories that for a phenolic material tested with a $\frac{1}{2}$ by $\frac{1}{2}$-in. bar on a 4-in. span support this indentation was usually between 7 and 15 per cent of the deflection used in calculating the modulus of elasticity. In some cases indentations as high as 25 per cent of the deflection were observed. Since a longer span results in both reduced loads and larger deflections for a given material and since the amount of indentation is largely a function of the load applied to the indenting edge, such an increase in the span-depth ratio from 8 to 16 will reduce this error to less than 1 per cent. Figure 10 of the Bakelite data indicates that if the modulus of elasticity is calculated from corrected and uncorrected deflections due to indentation of the loading edges, with a span-depth ratio of 8, the error introduced in modulus calculations is approximately 10 per cent while with a ratio of 16 the error is negligible. Thus, the use of the larger ratio obviates the necessity for determining the amount of indentation for each test and relieves the laboratory from considerable extra work.

Because of the above information obtained from theory and experiment the members of the section are suggesting that a span-depth ratio of 16 be used in making modulus of rupture and modulus of elasticity measurements.

Acknowledgments:

The author wishes to express appreciation to Messrs. Anderson of Westinghouse Electric and Manufacturing Co., Clark of Rensselaer Polytechnic Institute, Nason of Monsanto Chemical Co., and Mains of National Vulcanized Fibre Co. for making available the information and data supplied from their test results. Originals of the curve sheets were supplied by the respective laboratories making the tests.

DISCUSSION

MR. PHILIP S. TURNER (*by letter*).[1]—Papers by Tucker[2] and Weibull[3] are of interest in regard to the effect of span-depth ratio and uniformity of test results. These papers demonstrate that the strength of any material, other than a perfectly flawless homogeneous one, and the uniformity of the results, will vary with the size of the specimen and the method of testing. The magnitude of the effects of nonhomogeneity will be different for each specific material.

If flawless homogeneous specimens were available the effect of plastic flow, large deformations, rates of loading and other variables could be determined within the limits of experimental error with a single test specimen. In this connection it is notable that the results for unfilled polystyrene and the unfilled cellulose acetate are much more consistent than the results for the filled materials. It is not to be inferred from this that the testing procedure of one laboratory is superior to another but that the variabilities of the unfilled materials are less than those of the reinforced or filled plastics. The unfilled plastic can, at least theoretically, be continuous and homogeneous, whereas this is an inherent impossibility for the reinforced and filled materials.

The laminated materials, as is indicated by the data for flexural strength reported by the National Vulcanized Fibre Laboratory, can be fairly uniform. The data reported by the Westinghouse Laboratory, which are consistent for the cellulose acetate but inconsistent for the other materials, suggest that samples of the latter were too small or the specimens inadequately sampled, although the same number of specimens may have been used in all cases.

The data contributed by the Bakelite Corp. are likewise consistent for cellulose acetate and to a lesser degree for injection-molded polystyrene but inconsistent for the molded phenolic compositions. Although the numerical data for the tests on the phenolic molding materials are not given, the plot of the individual results serves to illustrate the unreliability of the data. The scattering does not indicate that the test method is any less precise than the method used for testing the cellulose acetate. The inference is necessarily that the materials are less uniform.

Statistical methods, when combined with adequate sampling, can be used to isolate the effect of independent variables, although the number of specimens required to remove uncertainty will vary with the standard deviation of the test results. For illustration, the data contributed by the Bakelite Corp. for the flexural strength of BM-021 at a span-depth ratio of 8 to 1 with $\frac{1}{2}$ by $\frac{1}{2}$-in. specimens, which were taken from the graph, have been used to calculate a tentative standard deviation. This turns out to be ± 700 psi. or a coefficient of variation, V, of 9 per cent of the average. The curve drawn through the points shows a variation of about 12 per cent between maximum and minimum values. The number of specimens required to establish the significance of the difference is given by the equation

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[1] Organic Plastics Section, National Bureau of Standards, Washington, D. C.

[2] J. Tucker, Jr., "Statistical Theory of the Effect of Dimensions and Method of Loading upon the Modulus of Rupture of Beams," *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 1072 (1941).

[3] W. Weibull, "A Statistical Theory of the Strength of Materials." *Proceedings*, Royal Swedish Inst. Engineering Research, No. 151 (1939).

$$N = \frac{18V^2}{(\text{difference})^2}$$

$$\therefore N = \frac{18 \times 81}{144}$$

$$= 10 \text{ specimens required}$$

Since only five specimens were used, this difference is not significant. The difference shown between tests at span-depth ratios of 8 to 1 and 16 to 1 is only 4 per cent and would require

$$N = \frac{18 \times 81}{16} = 90$$

specimens at each span-depth ratio. If fewer than the required number of specimens is used, the results may turn out to be inconsistent; as shown by the data for BM-3510.

The National Vulcanized Fibre Laboratory is to be commended for presenting data indicating the precision of their results. The presentation of data in the form of curves drawn through average values tends to convey an erroneous impression of the significance of the results and may lead to false conclusions based on inadequate data.

The variations in flexural properties peculiar to plastics are superimposed on a different type of variation due to nonhomogeneity which is common to all imperfect materials in varying degrees. The latter effect may be by far the most important, but until its magnitude is determined statistically the effect of the variable being studied cannot be determined with any certainty.

REPORT OF COMMITTEE E-3
ON
CHEMICAL ANALYSIS OF METALS*

Committee E-3 on Chemical Analysis of Metals held one meeting during the year on June 27, 1944, in New York, N. Y., during the annual meeting of the Society.

In addition to the meeting of the full committee, meetings of four divisions and ten subcommittees were held during the year.

Committee E-3 in conjunction with Committee E-2 on Spectrographic Analysis sponsored a Symposium on Analytical Colorimetry and Photometry[1] at the 1944 Annual Meeting in New York. Interest in this symposium as evidenced by the attendance exceeded expectations. A special committee under the chairmanship of D. R. Evans worked on the arrangements for the symposium and on the editing of the papers for publication.

The following officers were elected for the ensuing two years:

Chairman, G. E. F. Lundell,
Vice-Chairman, C. B. Francis,
Vice-Chairman, H. A. Bright,
Secretary, J. W. Stillman.

Seven new members and one consulting member were added to the committee during the year. Three members and one consulting member have been dropped from the committee. One member in the armed services was transferred to inactive status. One member was lost by death. The membership of the committee at the end of the year was 79.

The loss of Mr. T. A. Wright by death will be greatly felt by the members of Committee E-3. Mr. Wright had been very active from the beginning in the affairs of Committee E-3 and had shared willingly in the responsibilities, not only of this committee but in its relation to other committees. Committee E-3 voted the following resolution to be sent to Lucius Pitkin, Inc.:

> It was with sincere regret that the members of Committee E-3 of the American Society for Testing Materials learned of the death of your President, Mr. Thomas A. Wright. His intense interest in all committee affairs was deeply appreciated and his good counsel and sound judgment will be sorely missed. We wish to extend to you our sincere sympathy in a loss so grave.
>
> Voted in committee assembled, Washington, D. C., June 26, 1945.

A similar resolution voted by the committee was also sent to Mrs. Wright.

On the expectation that the Book of A.S.T.M. Methods of Chemical Analysis of Metals will be issued in a new edition in 1946, the divisions and the subcommittees have been actively at work on methods to be included in this new edition. Considerable progress was made during the year on revisions to bring the present procedures up to date and on new chemical methods, including a number of photometric methods.

RECOMMENDATIONS AFFECTING STANDARDS

As the result of the year's work, the committee is recommending the adoption as standard of nine tentative methods of chemical analysis of metals and the immediate adoption of revisions in one standard, as listed in Table I.

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* Presented at the Forty-Eighth Annual Meeting of the Society, June 27, 1945.

[1] *Proceedings*, Am. Soc. Testing Mats. Vol. 44, p. 709 (1944); also issued as separate publication.

These recommendations have been submitted to letter ballot of the committee which consists of 79 members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Not Voting
I. ADOPTION OF TENTATIVES AS STANDARD			
Chemical Analysis of Silver Solders (B 81 – 36 T)	43	0	12
Chemical Analysis for Selenium in Steel (E 30 – 43 T)	39	0	15
Chemical Analysis of Aluminum and Aluminum Alloys (E 34 – 42 T):			
Adoption as standard	49	1	7
Addition of titanous chloride procedure for iron	45	0	9
Chemical Analysis of Magnesium and Magnesium Alloys (E 35 – 42 T)	49	0	8
Chemical Analysis of Brasses (E 36 – 42 T)	54	0	0
Chemical Analysis of Pig Lead (E 37 – 42 T)	47	0	10
Chemical Analysis of Nickel (E 39 – 42 T)	51	0	3
Chemical Analysis of Slab Zinc (Spelter) (E 40 – 42 T)	51	0	3
Chemical Analysis of Zinc-Base Die-Casting Alloys (E 47 – 42 T)	51	0	3
II. REVISION OF STANDARD, IMMEDIATE ADOPTION			
Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron (E 30 – 42)	38	0	16

ACTIVITIES OF DIVISIONS AND SUBCOMMITTEES

Division A on Ferrous Metals (Arba Thomas, chairman).—The Ferrous Division held two meetings during the year, one at Pittsburgh, Pa., in January and the other at Washington, D. C., in June, 1945. Both meetings were well attended and keen interest was shown in the work of the division.

During the year the efforts of the division were concentrated on the selection and development of a combustion method for the determination of sulfur in iron and steel. As a result, a method was approved at the June meeting covering the determination of sulfur in steels only, and this will be submitted to a letter ballot of the Division and Committee E-3 for publication as tentative.[2] It is anticipated that in the near future additions will be made which will include procedures for determining sulfur in pig and cast iron.

A method for the determination of nitrogen in steel has also been completed and approved by letter ballot of the division. This method will be recommended for publication as tentative.[2]

Several subcommittee groups made a very careful review of the present Standard Methods of Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron (E 30 – 42) and presented recommendations as to modifications which are recommended for immediate adoption.[3] No serious criticisms of the present published methods were made but a number of minor improvements in details of certain procedures were suggested and approved. One important change was a decision to omit the direct cyanide titration method for nickel. It was conceded that this was a useful control method but could hardly be classified as a standard or umpire method which would fulfill the standard A.S.T.M. requirements.

Consideration is being given to a method for the determination of tungsten in certain complex alloy steels containing columbium and molybdenum.

The division has also completed a revision in the Standard Methods of Chemical Analysis of Ferro-Alloys (E 31 – 42) which will include a change in the method for determination of phosphorus in ferrovanadium, and a few minor improvements in other procedures. This revision will be presented later in the year[2] and in order to have the changes included immediately in Methods E 31 they will be reverted to tentative.

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[2] See Editorial Note, p. 394.

[3] The revisions have been incorporated in the revised methods which appear in the 1946 Book of A.S.T.M. Methods of Chemical Analysis of Metals.

Considerable progress has been made in the development of a standard method for the determination of tin in low-alloy and stainless steels. Most of the experimental work has been completed by the members of the subgroup responsible for this procedure and it is anticipated that the proposed method will be ready for letter ballot action later in the year.

The subgroup responsible for the development of a method for the determination of aluminum in high-alloy steels of the stainless type has accumulated considerable data and two methods have been selected for consideration by the Division. It is hoped that a tentative method will be ready for letter ballot action later in the year.

The subgroups in charge of the development of a method for the determination of bismuth in certain types of free-machining steel have delayed action for the time being in view of the demands of war work.

The question of tolerances that may be expected with the use of the standard A.S.T.M. methods was considered but it was felt that the concentrated effort of the Division on the problem would be required before definite progress could be made.

Some interest has been indicated in the determination of beryllium and a subgroup chairman was appointed to take up this problem.

Division B on Non-Ferrous Metals (D. R. Evans, chairman).—The Non-Ferrous Division held one meeting during the year at Washington, D. C., in June, 1945, but the members of the Division have been very active through the subcommittees reviewing the present published methods and working towards necessary revisions. A number of the present tentative methods for the analysis of non-ferrous metals were approved for adoption as standard, the titles of which are given in Table I. The Methods of Chemical Analysis of Aluminum and Aluminum Alloys (E 34 – 42 T) were adopted with the addition of a titanous chloride procedure for iron.

During the year methods for the determination of iron, manganese, nickel, phosphorus, arsenic, antimony, and tin have been prepared for addition to the Methods of Chemical Analysis of Special Brasses and Bronzes[2] which are to be submitted for publication as tentative and included in the new edition of the Book of Methods of Chemical Analysis of Metals.

The Tentative Method for Battery Assay of Copper (B 34 – 36 T) has been revised[2] and now applies to the analysis of material having a copper content of 99.4 per cent and over.

The scope of compositions of copper-nickel and copper-nickel-zinc alloys to be analyzed has been determined and progress is being made on the assembly of these analytical methods.

Methods for the chemical analysis of white metal bearing alloys are in the process of being revised.[2] A polarographic method for zinc and a new photometric method for aluminum in lead-tin alloys are being tested. When this work has been completed, revisions in the Tentative Methods of Chemical Analysis of Lead- and Tin-Base Solder Metals (E 46 – 42 T), and new Tentative Methods for Chemical Analysis of White Bearing Metals will be ready for letter ballot.[2]

Subcommittee B-7 has been very active in the development of photometric methods. In addition to preparing a Recommended Practice of Photometric Methods for Chemical Analysis of Metals, the subcommittee has in process of development the following photometric methods:

Analysis of copper and copper-base alloys,
Analysis of magnesium and magnesium-base alloys,
Bismuth in lead by the thiourea method,
Iron in slab zinc (spelter),
Iron in copper-nickel alloys, and
Iron in lead- and tin-base alloys.

It is expected that the above will be completed in time for publication[2] in the new edition of the Book of Chemical Methods. The cooperative data obtained in the study of these several methods will be collected and published in the 1946 Report of Committee E-3.

A special committee consisting of S. E. Q. Ashley, M. G. Mellon, J. W. Stillman, and P. J. Smith was appointed to advise and assist Subcommittee B-7 in the use of correct terminology and nomenclature in connection with its work.

Division C on Sampling completed a letter ballot on Methods of Sampling Slab Zinc which will be submitted for publication as tentative later in the year.[2]

The Proposed Methods of Sampling Wrought Metals and Alloys for Determination of Chemical Composition will be recommended for publication as tentative.[2]

Due to the death of T. A. Wright it is expected that W. C. Bowden, Jr. will be appointed as chairman of this division.

Division D on General Analytical Methods is responsible for the Tentative Recommended Practices for Apparatus and Reagents for Chemical Analysis of Metals (E 50 – 43 T). In line with changes in the companion methods of chemical analysis several minor revisions in this recommended practice will be made later in the year.[2] The officers of this division B. L. Clarke, chairman and J. W. Stillman, secretary, have asked to be relieved of this assignment. It is expected that S. E. Q. Ashley, and Clavin Sterling will be appointed as chairman and secretary, respectively. It is planned to reorganize the work of this division during the coming year.

This report has been submitted to letter ballot of the committee which consists of 79 members; 49 members returned their ballot, of whom 48 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

G. E. F. LUNDELL,
Chairman.

J. W. STILLMAN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-3 presented to the Administrative Committee on Standards the following recommendations:

Tentative Method for:
Determination of Nitrogen in Steel (E 30 – 45 T), and
Photometric Determination of Bismuth in Pig Lead (E 58 – 45 T)

These recommendations were accepted by the Standards Committee on August 27, 1945, and the new tentatives will appear in the 1946 Edition of the Book of A.S.T.M. Methods of Chemical Analysis of Metals under the designations indicated above.

On January 10, 1946, the Standards Committee accepted the recommendation of Committee E-3 that the Tentative Methods of Battery Assay of Copper (B 34 – 36 T) be revised and superseded by Tentative Methods of Chemical Analysis of Copper (Electrolytic Determination of Copper) (E 53 – 45 T). At the same time, the Tentative Photometric Methods for Chemical Analysis of Copper and Copper-Base Alloys (E 62 – 46 T) was accepted. These methods will appear in the 1946 Book of A.S.T.M. Methods of Chemical Analysis of Metals under the designations indicated above.

REPORT OF COMMITTEE E-10
ON
STANDARDS*

Committee E-10 on Standards continues to receive a large number of recommendations with respect to tentative specifications and methods. In view of the O.D.T. travel restrictions, a number of the Society's larger committees have not been able to hold customary meetings. However, these committees have taken advantage of the provision of the Regulations which permits the reference of standards recommendations to letter ballot in the standing committees, provided the vote in the subcommittee is sufficiently clear, without first holding a meeting of the main committee. This has contributed to a great number of recommendations being submitted to Committee E-10 during the year and no doubt will continue to operate in this way even after the present emergency is over. Since all recommendations dealing with emergency standards and emergency provisions must also receive the attention of Committee E-10, that committee has had an extremely full docket as will be noted later in the report where the various actions are set forth as a matter of record. It will be noted that fourteen of the emergency standards have proved to be of permanent value and have been accepted for publication as tentative during the year. Likewise a number of the emergency alternate provisions have been withdrawn as such and incorporated in the standards themselves. No doubt similar action will be taken with respect to a number of other emergency provisions still remaining on the books, and it is expected that with improved conditions, the remainder will be promptly discontinued. In accordance with the Procedure for Emergency Provisions and Standards all such provisions are subject to annual review and in order to be continued in effect must be reaffirmed by letter ballot vote of the sponsoring group, and the committee's recommendations submitted to Committee E-10.

Only one meeting of the committee was held during the year, much of its work having been handled by correspondence. At that meeting, held in Philadelphia, Pa., on August 28, 1944, H. S. Vassar was re-elected chairman of Committee E-10 to serve until June, 1945. The membership on Committee E-10 of R. D. Bonney and F. H. Jackson expired last year. However, they were both reappointed by the Executive Committee of the Society to serve as members of Committee E-10 for a three-year term expiring in 1947.

ALL 1945 RECOMMENDATIONS RELATING TO TENTATIVES TO BE SUBMITTED TO COMMITTEE E-10

In lieu of a regular Annual Meeting with technical sessions, this year it is planned to hold a one-day business meeting in New York, N. Y., on Wednesday, June 27. At this meeting only those recommendations from standing committees that have to do with the adoption of standards and revision of standards, which according to the Regulations of the Society require Annual Meeting action for reference to letter ballot, will be acted upon. All recommendations dealing with tentatives, as for example the submission of new tentative specifications and methods of test or revisions of existing tentative specifications and methods, will be referred to Committee E-10. These recommendations will be considered at a special meeting of Committee E-10 called for Wednesday, June 27, 1945, in New York, N. Y., at which time consideration will also be given to any emergency recommendations.

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* Presented at Forty-Eighth Annual Meeting of the Society, June 27, 1945.

REVIEW OF A.S.T.M. STANDARDIZATION ACTIVITIES

A summary of new and revised tentatives submitted at the 1944 Annual Meeting was included in the August issue of the ASTM BULLETIN together with a review of standardization work of the various committees, with statements concerning new standards in prospect. Much of the information, particularly with respect to standardization projects under development in committees, is furnished by the standing committees subsequent to the Annual Meeting and takes advantage of the fact that many committees customarily plan their next year's work at committee meetings held during the Annual Meeting.

At the present time, it is possible to make only a preliminary estimate, in terms of new and revised standards, of the volume of standardization work accomplished during the year which will be reported to the Society at the time of the Annual Meeting. The reports of standing committees to be presented at the Annual Meeting include recommendations substantially as follows:

New tentatives	58
Revisions of tentatives	56
Tentatives adopted as standard	36
Tentative revisions of standards	15
Revisions of standards recommended for adoption as standard	39
Withdrawals of standards and tentatives	2

There are at present 798 standards and 463 tentatives of the Society, making a total of 1261, and if the above recommendations are approved, this total will become 1317.

PROMOTION AND EXPANSION OF STANDARDIZATION ACTIVITIES

Activities in Field of Ultimate Consumer Goods.—During the year steps have been taken to extend the activities of the Society in the development of standard tests and specifications for ultimate consumer goods. As mentioned in the Report of the Executive Committee,[1] an Administrative Committee on Ultimate Consumer Goods has been formed to plan and direct the development of this program through extension of present committee activities and, when advisable, through the establishment of new committees.

Detailed information concerning the activities of the Society in this field will appear from time to time in the ASTM BULLETIN.

Sulfur Cements.—In view of war-time conditions, no further steps have been taken looking toward the organization of the committee on sulfur cements which was authorized several years ago.

Leather.—In view of the industrial use of leather for cushioning, belting, gaskets, etc., it was suggested that a canvass be conducted to determine the desirability of A.S.T.M. entering this field. This will be done through the medium of the ASTM BULLETIN.

Asbestos Cement Products.—The use of asbestos cement as a building material for roofing, water pipes, etc., is of interest to a number of the committees of the Society. Rather than to refer the subject to the different committees according to use, consideration is being given to the desirability of forming an entirely new committee on cement asbestos products to include sheet and shingles as well as pipe, block asbestos, etc.

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[1] See p. 21.

CONSIDERATION OF NEW AND REVISED TENTATIVES

The following new specifications and methods of test were accepted by Committee E-10 during the year for publication as tentative:

Tentative Specifications for:

Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 - 44 T), submitted jointly by Committee A-1 on Steel and Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys,

Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 - 44 T), submitted jointly by Committee A-1 and Committee A-10,

Seamless and Welded Austenitic Stainless Steel Tubing for the Dairy and Food Industry (A 270 - 44 T), submitted jointly by Committee A-1 and Committee A-10,

Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 - 44 T), submitted jointly by Committee A-1 and Committee A-10,

Carbon-Steel Blooms, Billets, and Slabs for Forgings (A 273 - 44 T), submitted by Committee A-1,

Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 274 - 44 T), submitted by Committee A-1,

Lightweight and Thin-Sectioned Gray Iron Castings (A 190 - 44 T), submitted by Committee A-3 on Cast Iron,

Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (A 276 - 44 T), submitted by Committee A-10,

Malleable Iron Flanges, Pipe Fittings, and Valve Parts (A 277 - 44 T), submitted by Committee A-7 on Malleable Iron Castings,

Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650 F. (A 278 - 44 T), submitted by Committee A-3,

Automotive Gray Iron Castings (A 159 - 44 T), submitted by Committee A-3,

Masonry Cement (C 91 - 44 T), submitted by Committee C-1 on Cement,

Standard Strength Clay Sewer Pipe (C 13 - 44 T), submitted by Committee C-4 on Clay Pipe,

Extra Strength Clay Pipe (C 200 - 44 T), submitted by Committee C-4,

GR-S (Synthetic Rubber) Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance Is Not Required (D 812 - 44 T), submitted by Committee D-11 on Rubber and Rubber-Like Materials,

Cast Allyl Plastic Sheets, Rods, Tubes, and Shapes (D 819 - 45 T), submitted by Committee D-20 on Plastics,

Tentative Methods of:

Magnetic Particle Testing and Inspection of Commercial Steel Castings (A 272 - 44 T), submitted by Committee A-1 on Steel,

Magnetic Particle Testing and Inspection of Heavy Steel Forgings (A 275 - 44 T), submitted by Committee A-1,

Total Immersion Testing of Stainless Steels (A 279 - 44 T), submitted by Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys,

Test for Resistivity of Copper and Copper-Alloy Electrical Conductors (B 193 - 44 T), submitted by Committee B-1 on Copper and Copper Alloy Wires for Electrical Conductors,

Test for Bonding Strength of Air-Setting Refractory Mortar (Wet Type) (C 198 - 45 T), submitted by Committee C-8 on Refractories,

Test for Refractoriness of Air-Setting Refractory Mortars (Wet Type) (C 199 - 45 T), submitted by Committee C-8,

Test for Thermal Conductivity of Refractories (C 201 - 45 T), submitted by Committee C-8,

Test for Thermal Conductivity of Fireclay Refractories (C 202 - 45 T), submitted by Committee C-8,

Sampling and Testing Turpentine (D 233 - 44 T), submitted by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Testing Veneer, Plywood, and Other Wood and Wood-Base Materials (D 805 - 44 T), submitted by Committee D-7 on Wood,

Test for Cement Content of Soil-Cement Mixtures (D 806 - 44 T), submitted jointly by Committee D-4 on Road and Paving Materials and Committee D-18 on Soils for Engineering Purposes,

Field Test for Tendency of Boiler Water to Cause Embrittlement Cracking of Steel (D 807 - 44 T), submitted by Committee D-19 on Water for Industrial Uses,

Test for Chlorine in Lubricating Oils by Bomb Method (D 808 - 44 T), submitted by Committee D-2 on Petroleum Products and Lubricants,

Chemical Analysis for Phosphorus in Lubricating Oils (D 809 - 44 T) submitted by Committee D-2, Chemical Analysis for Lead, Copper, and Iron in Lubricating Oils (D 810 - 44 T), submitted by Committee D-2,

Chemical Analysis for Metals in Lubricating Oils (D 811 - 44 T), submitted by Committee D-2,

Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Crack Growth (D 813 - 44 T), submitted by Committee D-11 on Rubber and Rubber-Like Materials,

Test for Permeability of Vulcanized Rubber or Synthetic Elastomers to Volatile Liquids (D 814 - 44 T), submitted by Committee D-11,

Test for Hydrogen Permeability of Rubber-Coated Fabrics (D 815 - 44 T), submitted by Committee D-11,

Testing Rubber Adhesives (D 816 - 44 T), submitted by Committee D-11,

Chemical Analysis of Soaps Containing Synthetic Detergents (D 820 - 45 T), submitted by Committee D-12 on Soaps and Other Detergents,

Test for Measuring the Flow Properties of Thermoplastic Molding Materials (D 569 - 44 T), submitted by Committee D-20 on Plastics,

Test for Deformation of Plastics Under Load (D 621 - 44 T), submitted by Committee D-20,

Test for Acetyl and Butyryl Content of Cellulose Acetate Butyrate (D 817 - 44 T), submitted by Committee D-20,

Tentative Recommended Practice for Molding Specimens of Phenolic Material (D 796 - 44 T), submitted by Committee D-20, and

Tentative Industrial Radiographic Terminology for Use in Connection with the Radiographic Inspection of Castings and Weldments (E 52 - 45 T), submitted by Committee E-7 on Radiographic Testing.

Revisions of the following tentatives and tentative revisions of standards were accepted by Committee E-10 during the year:

Tentative Specifications for:

Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 - 44 T), submitted by Committee A-1 on Steel,

Carbon-Steel Seamless Drum Forgings (A 266 - 44 T), submitted by Committee A-1,

Iron and Steel Arc-Welding Electrodes (A 233 - 45 T), submitted by the Joint A.W.S. - A.S.T.M. Committee on Filler Metal,

Oxygen-Free Electrolytic Copper Wire Bars, Billets, and Cakes (B 170 - 44 T), submitted by Committee B-2 on Non-Ferrous Metals and Alloys,

Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 - 44 T), submitted by Committee B-5 on Copper and Copper Alloys, Cast and Wrought,

Brass Sheet and Strip (B 36 - 44 T), submitted by Committee B-5,

Leaded Brass Sheet and Strip (B 121 - 44 T), submitted by Committee B-5,

Gilding Metal Strip (B 130 - 44 T), submitted by Committee B-5,

Aluminum Bronze Sheet and Strip (B 169 - 44 T), submitted by Committee B-5,

Copper Sheet, Strip, and Plate (B 152 - 44 T), submitted by Committee B-5,

Naval Brass Rods, Bars, and Shapes (B 21 - 44 T), submitted by Committee B-5,

Copper Rods, Bars, and Shapes (B 133 - 44 T), submitted by Committee B-5,

Brass Wire (B 134 - 44 T), submitted by Committee B-5,

Phosphor Bronze Rods, Bars, and Shapes (B 139 - 44 T), submitted by Committee B-5,

Aluminum Bronze Rods, Bars, and Shapes (B 150 - 44 T), submitted by Committee B-5,

Copper-Nickel-Zinc Alloy Rod, Bar, and Wire (B 151 - 44 T), submitted by Committee B-5,

Phosphor Bronze Wire (B 159 - 44 T), submitted by Committee B-5,

Copper Bus Bars, Rods, and Shapes (B 187 - 44 T), submitted by Committee B-5,

Copper Bus Pipes and Tubes (B 188 - 44 T), submitted by Committee B-5,

Aluminum-Base Alloys in Ingot Form for Sand Castings (B 58 - 44 T), submitted by Committee B-7 on Light Metals and Alloys, Cast and Wrought,

Aluminum-Base Alloys in Ingot Form for Permanent Mold Castings (B 112 - 44 T), submitted by Committee B-7,

Aluminum-Base Alloys in Ingot Form for Die Castings (B 125 - 44 T), submitted by Committee B-7,

Air-Setting Refractory Mortars (Wet Type) for Boiler and Incinerator Services (C 178 - 45 T), submitted by Committee C-8 on Refractories,

Expanded or Exfoliated Vermiculite Thermal Insulating Cement (C 196 - 44 T), submitted by Committee C-16 on Thermal Insulating Materials,

Wood to be Used as Panels in Weathering Tests of Paints and Varnishes (D 358 - 44 T), submitted by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Asphalt Roofing Surfaced with Coarse Mineral Granules (D 249 - 44 T), submitted by Committee D-8 on Bituminous Waterproofing and Roofing Materials,

Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 – 44 T), submitted by Committee D-8,

Asphalt Shingles Surfaced with Coarse Mineral Granules (D 225 – 44 T), submitted by Committee D-8,

Flexible Treated Cotton and Rayon Sleeving Used in Electrical Insulation (D 372 – 44 T), submitted by Committee D-9 on Electrical Insulating Materials,

Black Bias-Cut Varnished Cloth Tape Used for Electrical Insulation (D 373 – 44 T), submitted by Committee D-9,

Laminated Thermosetting Materials (D 709 – 44 T), submitted jointly by Committee D-9 and Committee D-20 on Plastics,

Cellular Rubber Products (D 798 – 44 T), submitted by Committee D-11 on Rubber and Rubber-Like Materials,

Vinyl Chloride-Acetate Resin Plastic Sheets (D 708 – 44 T), submitted by Committee D-20 on Plastics,

Vinyl Chloride-Acetate Resin Molding Compounds (D 728 – 44 T), submitted by Committee D-20,

Tentative Methods of:

Test for Thermal Conductivity of Insulating Fire Brick (C 182 – 45 T), submitted by Committee C-8 on Refractories,

Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 – 44 T), submitted by Committee D-8 on Bituminous Waterproofing and Roofing Materials,

Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 44 T), submitted by Committee D-9 on Electrical Insulating Materials,

Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 – 44 T), submitted by Committee D-9,

Conditioning and Classifying for Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 44 T), submitted jointly by Committee D-9 and Committee D-20 on Plastics,

Test for Heat Distortion Temperature of Plastics (D 648 – 44 T), submitted jointly by Committee D-9 and Committee D-20,

Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 – 44 T), submitted by Committee D-11 on Rubber and Rubber-Like Materials,

Testing Hard Rubber Products (D 530 – 44 T), submitted by Committee D-11,

Testing Automotive Hydraulic Brake Hose (D 571 – 44 T), submitted by Committee D 11,

Testing Cellular Rubber Products (D 552 – 44 T), submitted by Committee D-11,

Test for Indentation of Rubber by Means of the Durometer (D 676 – 44 T), submitted by Committee D-11,

Test for Resistance of Plastics to Accelerated Service Conditions (D 756 – 44 T), submitted by Committee D-20 on Plastics,

Test for Colorfastness of Plastics to Light (D 620 – 45 T), submitted by Committee D-20,

Tentative Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 – 44 T), submitted by Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys,

Tentative Classification of Insulating Back-Up Block and Insulating Fire Brick (C 155 – 45 T), submitted by Committee C-8 on Refractories,

Tentative Definitions of Terms Relating to Soaps and Other Detergents (D 459 – 45 T), submitted by Committee D-12 on Soaps and Other Detergents,

Tentative Revisions of Standard Specifications for:

Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not Including 30 in.) (A 139 – 42), submitted by Committee A-1 on Steel,

Steel for Bridges and Buildings (A 7 – 42), submitted by Committee A-1,

Mild Steel Plates (A 10 – 39), submitted by Committee A-1,

Low Tensile Strength Carbon-Steel Plates of Structural Quality for Welding (A 78 – 43), submitted by Committee A-1,

Low-Alloy Structural Steel (A 242 – 42), submitted by Committee A-1,

Carbon-Steel Forgings for General Industrial Use (A 235 – 42), submitted by Committee A-1,

Carbon-Steel Forgings for Locomotives and Cars (A 236 – 42), submitted by Committee A-1,

Alloy-Steel Forgings for General Industrial Use (A 237 – 42), submitted by Committee A-1,

Alloy-Steel Forgings for Locomotives and Cars (A 238 – 42), submitted by Committee A-1,

Carbon-Steel and Alloy-Steel Ring and Disk Forgings (A 243 – 43), submitted by Committee A-1,

Commercial Quality Hot-Rolled Bar Steels (A 107 – 42), submitted by Committee A-1,

Commercial Cold-Finished Bar Steels and Cold-Finished Shafting (A 108 – 36), submitted by Committee A-1, Wrought Iron Plates (A 42 – 39), submitted by Committee A-2 on Wrought Iron,

Manganese Bronze Rods, Bars, and Shapes (B 138 – 43), submitted by Committee B-5 on Copper and Copper Alloys, Cast and Wrought,

Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 – 43), submitted by Committee B-5,

Zinc Sulfide Pigments (D 477 – 41), submitted by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Tentative Revisions of Standard Methods of:

Test for Magnetic Properties of Iron and Steel (A 34 – 44), submitted by Committee A-6 on Magnetic Properties,

Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 43), submitted by Committee D-9 on Electrical Insulating Materials,

Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 43), submitted by Committee D-9,

Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (D 573 – 42), submitted by Committee D-11 on Rubber and Rubber-Like Materials,

Sampling and Chemical Analysis of Soaps and Soap Products (D 460 – 44), submitted by Committee D-12 on Soaps and Other Detergents, and

Standard Definitions of Terms Relating to Refractories (C 71 – 42), submitted by Committee C-8 on Refractories.

The withdrawal of the following standards and tentative specifications was approved by Committee E-10:

Tentative Specifications for Carbon-Steel and Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 248 – 41 T), recommended by Committee A-1 on Steel,

Standard Specifications for:

Lightweight and Thin-Sectioned Gray Iron Castings (A 190 – 40), recommended by Committee A-3 on Cast Iron,

Clay Sewer Pipe (C 13 – 40), recommended by Committee C-4 on Clay Pipe,

Wood to be Used as Panels in Weather Tests of Paints and Varnishes (D 358 – 38), recommended by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Standard Methods of:

Sampling and Testing Turpentine (D 233 – 36), recommended by Committee D-1,

Test for Measuring Flow Temperatures of Thermoplastic Molding Materials (D 569 – 43), recommended by Committee D-20 on Plastics, and

TABLE I.—ACTIONS UNDER EMERGENCY PROCEDURE.

Designation	Emergency Alternate Provisions in	Committee
	Standard Specifications for:	
EA – A 213a	Seamless Alloy-Steel Boiler and Superheater Tubes (A 213 – 44)	A-1
EA – A 249a	Atomic-Hydrogen-Arc-Welded and Electric-Resistance-Welded Alloy-Steel Boiler and Superheater Tubes (A 249 – 44)	A-1
EA – A 70a	Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A 70 – 44)	A-1
EA – A 1a	Open-Hearth Carbon-Steel Rails (A 1 – 39)	A-1
EA – B 23b	White Metal Bearing Alloys (Known Commercially as "Babbitt Metal") (B 23 – 26)	B-2
EA – B 62b	Composition Brass or Ounce Metal Castings (B 62 – 44)	B-5
EA – D 69b	Friction Tape for General Use for Electrical Purposes (D 69 – 38)	D-11
EA – E 1	A.S.T.M. Thermometers (E 1 – 44)	E-1
	Tentative Specifications for:	
EA – A 274	Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 274 – 44 T)	A-1
EA – A 158a	Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 – 44 T)	A-1
EA – A 268	Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 – 44 T)	A-1 & A-10
EA – A 269	Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 44 T)	A-1 & A-10
EA – A 270	Seamless and Welded Austenitic Stainless Steel Tubing for the Dairy and Food Industry (A 270 – 44 T)	A-1 & A-10
EA – A 271	Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 44 T)	A-1 & A-10
EA – B 32b	Soft Solder Metal (B 32 – 40 T)	B-2
EA – B 22b	Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 – 44 T)	B-5
EA – B 143b	Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 – 44 T)	B-5
EA – B 144b	High-Leaded Tin-Bronze Sand Castings (B 144 – 44 T)	B-5
EA – B 145b	Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 – 44 T)	B-5
EA – B 146b	Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 44 T)	B-5
EA – D 224b	Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 – 44 T)	D-8
EA – D 249b	Asphalt Roofing Surfaced with Coarse Mineral Granules (D 249 – 44 T)	D-8
EA – D 754	Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 – 43 T)	D-11
EA – D 755	Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 – 44 T)	D-11
EA – D 574b	Insulated Wire and Cable: Ozone-Resistant Type Insulation (D 574 – 40 T)	D-11
	Standard Method of:	
EA – D 97	Test for Cloud and Pour Points (D 97 – 39)	D-2
EA – D 470	Testing Rubber Insulated Wire and Cable (D 470 – 41)	D-11

Test for Deformation of Plastics Under Load at Elevated Temperatures (D 621 – 43), recommended by Committee D-20.

ACTIONS UNDER EMERGENCY PROCEDURE

Emergency Alternate Provisions.—As a matter of record, the emergency alternate provisions accepted by Committee E-10 during the year are listed in the accompanying Table I.

The following emergency alternate provisions were withdrawn during the year:

Designation	Emergency Alternate Provisions in	Committee
	Standard Specifications for:	
EA – A 204	Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 42)	A-1
EA – A 203	Low-Carbon Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 42)	A-1
EA – A 67	Steel Tie Plates (A 67 – 33)	A-1
EA – A 241	Hot-Worked High-Carbon Steel Tie Plates (A 241 – 41)	A-1
EA – A 30	Boiler and Firebox Steel for Locomotives (A 30 – 42)	A-1
EA – A 201	Carbon-Silicon Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 43)	A-1
EA – A 202	Chrome - Manganese - Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 – 39)	A-1
EA – A 212	High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 4½ in. and Under in Thickness) (A 212 – 39)	A-1
EA – A 190	Lightweight and Thin-Sectioned Gray-Iron Castings (A 190 – 40)	A-3
EA – A 116	Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 – 39)	A-5
EA – A 121	Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 – 39)	A-5
EA – A 240a	Corrosion-Resisting, Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip, for Fusion-Welded Unfired Pressure Vessels (A 240 – 43)	A-10
EA – B 8	Concentric-Lay Stranded Copper Conductors, Hard, Medium-Hard or Soft (B 8 – 41)	B-1
EA – B 100	Rolled Copper-Alloy Bearing and Expansion Plates for Bridge and Other Structural Uses (B 100 – 43)	B-5
EA – B 103	Phosphor Bronze Sheet and Strip (B 103 - 43)	B-5
EA – B 60a	Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (B 60 – 41)	B-5
EA – B 85a	Aluminum-Base Alloy Die Castings (B 85 – 42)	B-6
EA – B 86b	Zinc-Base Alloy Die Castings (B 86 – 43)	B-6
EA – D 533	Built Soap, Powdered (D 533 – 41)	D-12
	Tentative Specifications for:	
EA – B 19	Cartridge Brass Sheet, Strip, and Disk (B 19 – 42 T)	B-5
EA – B 36	Brass Sheet and Strip (B 36 – 43 T)	B-5
EA – B 30	Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 42 T)	B-5
EA – B 121	Leaded Brass Sheet and Strip (B 121 – 43 T)	B-5
EA – B 124	Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 – 42 T)	B-5
EA – B 129	Cartridge Brass Cartridge Case Cups (B 129 – 43 T)	B-5
EA – B 130	Gilding Metal Sheet and Strip (B 130 – 43 T)	B-5
EA – B 131	Gilding Metal Bullet Jacket Cups (B 131 – 43 T)	B-5
EA – B 133	Copper Rods, Bars, and Shapes (B 133 – 42 T)	B-5
EA – B 134	Brass Wire (B 134 – 42 T)	B-5
EA – B 139	Phosphor Bronze Rods, Bars, and Shapes (B 139 – 42 T)	B-5
EA – B 151	Copper-Nickel-Zinc Alloy Rod and Wire (B 151 – 42 T)	B-5
EA – B 152	Copper Sheet, Strip, and Plate (B 152 – 41 T)	B-5
EA – B 159	Phosphor Bronze Wire (B 159 – 43 T)	B-5
EA – B 169	Aluminum Bronze Sheet and Strip (B 169 – 42 T)	B-5
EA – D 225	Asphalt Shingles Surfaced with Coarse Mineral Granules (D 225 – 41 T)	D-8
	Tentative Methods of:	
EA – D 228	Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 – 42 T)	D-8

Emergency Standards.—Three emergency standards have been accepted by Committee E-10 during the year as follows:

Emergency Specifications for:

Communication and Signal Pin-Type Lime-Glass Insulators (ES – 41), submitted by Committee D-9 on Electrical Insulating Materials,

Emergency Methods of:

Test for Isopentane and Benzene Insolubles in Used Lubricating Oils (ES – 42), submitted by Committee D-2 on Petroleum Products and Lubricants, and

Air-Ignition Test for Determination of Sulfated Residue from Lubricating Oils (ES – 43), submitted by Committee D-2.

The following two emergency methods which had been approved and issued on a restricted basis in 1943 have been released for general publication during the past year and appear in the 1944 Book of A.S.T.M. Standards, Part III:

Emergency Methods of:

Test for Olefins, Aromatics, Paraffins, and Naphthenes in Aviation Gasoline (Without Distillation into Fractions) (ES - 45), submitted by Committee D-2 on Petroleum Products and Lubricants, and

Test for Benzene, Toluene, and Higher-Boiling Aromatics in Aviation Gasoline (ES - 46) submitted by Committee D-2.

Revisions in the Emergency Specifications for Carbon-Steel Forgings for Rings for Main Reduction Gears (ES - 23a), submitted by Committee A-1 on Steel, were accepted by Committee E-10 during the year.

As indicated earlier in the report, a number of emergency standards have been changed in status and issued as tentative during the year. As a matter of record, there is given below a list of emergency standards that have been discontinued as such and issued as tentative:

Emergency Specifications for:

Lead-Coated and Lead-Alloy-Coated Copper Wire for Electrical Purposes (ES - 1a) [replaced by Tentative Specifications B 189 - 44 T], recommended by Committee B-1 on Copper and Copper Alloy Wires for Electrical Conductors,

Lead Coating (Hot-Dip) on Iron or Steel Hardware (ES - 2) [replaced by Tentative Specifications A 267 - 44 T], recommended by Committee A-5 on Corrosion of Iron and Steel,

85 per cent Magnesia Thermal Insulating Cement (ES - 8) [replaced by Tentative Specifications C 193 - 44 T], recommended by Committee C-16 on Thermal Insulating Materials,

Long-Fiber Asbestos Thermal Insulating Cement (ES - 9) [replaced by Tentative Specifications C 194 - 44 T], recommended by Committee C-16,

Mineral Wool Thermal Insulating Cement (ES - 10) [replaced by Tentative Specifications C 195 - 44 T], recommended by Committee C-16,

Expanded or Exfoliated Mica Thermal Insulating Cement (ES - 11) [replaced by Tentative Specifications C 196 - 44 T], recommended by Committee C-16,

Diatomaceous Silica Thermal Insulating Cement, for Use from 600 to 1200 F. (ES - 12) [replaced by Tentative Specifications C 197 - 44 T], recommended by Committee C-16,

Diatomaceous Silica Thermal Insulating Cement, for Use from 1200 to 1900 F. (ES - 13) [replaced by Tentative Specifications C 197 - 44 T], recommended by Committee C-16,

Malleable Iron Flanges, Pipe Fittings, and Valve Parts (ES - 20) [replaced by Tentative Specifications A 277 - 44 T], recommended by Committee A-7 on Malleable Iron Castings,

Emergency Methods of:

Conducting Salt Spray Tests on Organic Protective Coatings (ES - 3) [replaced by Tentative Method B 117 - 44 T], recommended by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Test for Chlorine in Lubricating Oils by Bomb Method (ES - 36) [replaced by Tentative Method D 808 - 44 T], recommended by Committee D-2 on Petroleum Products and Lubricants,

Test for Phosphorus in Lubricating Oils (ES - 37) [replaced by Tentative Method D 809 - 44 T], recommended by Committee D-2,

Test for Lead, Copper, and Iron in Lubricating Oils (ES - 38) [replaced by Tentative Method D 810 - 44 T], recommended by Committee D-2, and

Test for Metals in Lubricating Oil (ES - 39) [replaced by Tentative Method D 811 - 44 T], recommended by Committee D-2.

Action was also taken to withdraw the Emergency Alternate Specifications for Portland Cement (EA - C 150), as recommended by Committee C-1 on Cement, inasmuch as Limitation Order L-179 of the War Production Board had been rescinded.

RELATIONS WITH THE AMERICAN STANDARDS ASSOCIATION

Revised Standards Submitted Under Proprietary Procedure.—The Society has been granted proprietary sponsorship for the revision of A.S.T.M. standards approved as American Standard under the existing standards procedure and, functioning as proprietary sponsor, has submitted to the American Standards Association during the year revisions of the following standards, all of which have been approved:

Standard Specifications for:

Carbon-Steel Castings for Miscellaneous Industrial Uses (ASTM A 27 – 44; ASA G50.1–1945),
Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A 70 – 44; G29.1–1945),
Carbon-Steel Castings for Valves, Flanges, and Fittings for High-Temperature Service (A 95 – 44; G17.1–1944),
Alloy-Steel Bolting Material for High-Temperature Service (A 96 – 44; G17.2–1944),
Alloy-Steel Castings for Structural Purposes (A 148 – 44; G52.1–1944),
Alloy-Steel Castings for Valves, Flanges, and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 – 44; G36.1–1944),
Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 – 44; G37.1–1944),
Carbon-Silicon Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 44; G31.1–1945),
Chrome-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 – 44; G32.1–1945),
Low-Carbon Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 44; G33.1–1945),
Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 44; G34.1–1945),
High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 4½ in. and Under in Thickness) (A 212 – 44; G35.1–1945),
Carbon-Steel Castings Suitable for Fusion Welding for Miscellaneous Industrial Uses (A 215 – 44; G51.1–1944),
Free-Cutting Brass Rod and Bar for Use in Screw Machines (B 16 – 44; H8.1–1944),
Hollow Load-Bearing Concrete Masonry Units (C 90 – 44; A79.1–1944),
Zinc Oxide (D 79 – 44; K22.1–1944),
Basic Sulfate White Lead (D 82 – 44; K47.1–1945),

Standard Methods of:

Sampling and Testing Brick (C 67 – 44; A82.1–1944),
Chemical Analysis of Dry Red Lead (D 49 – 44; K16.1–1944), and
Testing Wool Felt (D 461 – 44; L16.1–1945).

Standards Submitted Under Sectional Committee Procedure.—Reports were received from four of the sectional committees for which the Society is sponsor or joint sponsor, submitting standards to the ASA for approval. These reports were transmitted to that association and the following standards have been approved for the first time or reapproved in revised form during the year as American Standard:

On the Recommendation of Sectional Committee A37 on Road and Paving Materials:

Standard Methods of Test for:

Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (ASTM C 131 – 44; ASA A37.7–1945), and
Ductility of Bituminous Materials (D 113 – 44; A37.11–1945).

On the Recommendation of Sectional Committee B36 on Standardization of Dimensions and Materials of Wrought-Iron and Wrought-Steel Pipe and Tubing:

Standard Specifications for:

Welded and Seamless Steel Pipe (ASTM A 53 – 44; ASA B36.1–1945),
Electric-Resistance-Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 – 44; B36.13–1945),
Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 – 44; B36.12–1945),
Electric-Resistance-Welded Steel Pipe (A 135 – 44; B36.5–1945),
Seamless Steel Boiler Tubes for High-Pressure Service (A 192 – 44; B36.14–1945),
Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 – 44; B36.15–1945).
Spiral-Welded Steel or Iron Pipe (A 211 – 44; B36.16–1945),
Seamless Alloy-Steel Boiler and Superheater Tubes (A 213 – 44; B36.17–1945), and
Electric-Resistance-Welded Steel Boiler and Superheater Tubes for High-Pressure Service (A 226 – 44; B36.18–1945),

On the Recommendation of Sectional Committee G8 on Specifications for Zinc Coating of Iron and Steel:

Specifications for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Uses (ASTM A 120 – 44; ASA G8.7–1945).

On the Recommendation of Sectional Committee Z11 on Petroleum Products and Lubricants: Standards Methods of:

Test for Viscosity by Means of the Saybolt Viscosimeter (ASTM D 88 - 44; ASA Z11.2-1944),
Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 - 44; Z11.20-1944),
Test for Sulfur in Petroleum Oils by Bomb Method (D 129 - 44; Z11.13-1944),
Test for Knock Characteristics of Motor Fuels (D 357 - 44; Z11.37-1944),
Test for Gum Content of Gasoline (D 381 - 44; Z11.36-1944),
Conversion of Kinematic Viscosity to Saybolt Furol Viscosity (D 666 - 44; Z11.53-1944), and
Test for Oil Content of Paraffin Wax (D 721 - 44; Z11.52-1944).

On the recommendation of Sectional Committee B36 on Standardization of Dimensions and Materials of Wrought-Iron and Wrought-Steel Pipe and Tubing, approval as American Standard of the obsolete Specifications for Forge-Welded Steel Pipe (A 136 - 34; B36.6-1935) and for Riveted Steel and Wrought-Iron Pipe (A 138 - 34; B36.8-1935) was withdrawn by the ASA.

In accordance with ASA procedure, the association has, on the recommendation of the Society, reaffirmed a number of A.S.T.M. standards which had been approved as American Standard and have stood four years or more without revision.

UNITED NATIONS STANDARDS COORDINATING COMMITTEE

The United Nations Standards Coordinating Committee was organized to promote the maximum possible coordination and unification of standards necessary for the war effort and the immediate post-war period. The membership of the UNSCC includes the national standardizing bodies of Australia, Brazil, Canada, China, Great Britain, New Zealand, South Africa, and the United States. The United States is represented through the American Standards Association. The national standardizing agencies of Russia and Mexico are considering membership in the UNSCC.

Suggestions have already been received from the various countries holding membership on the committee that consideration be given to holding discussions on an international level on the following subjects, the initiation of such discussions being contingent upon interest being expressed by at least two of the countries represented on the UNSCC:

(*1*) Unification of national terms and definitions for heat treatment of steel—suggested by the British Standards Institution: The Society has been asked by the ASA to develop the American viewpoint as to whether this country would wish to have discussions on an international level with respect to definitions of terms in this field. A canvass is being conducted and a number of favorable replies have been received together with the suggestion that the discussions be extended to include heat treatment terms of metals rather than confining them to steel.

(2) Standardization of grades of shellac and methods of testing—suggested by the British Standards Institution: The Society was asked to develop the American viewpoint as to whether this country would wish to participate in discussions with respect to grading and testing of shellac. Based upon a favorable canvass, it is expected that a committee will shortly be appointed under the supervision of the A.S.T.M. to develop recommendations to be presented for international consideration.

(3) International agreement on methods of expressing moisture content of wool knitting yarns—suggested by the Standards Association of Australia: A conference of American wool interests, at which A.S.T.M. was represented by Fred Noechel, was held in New York,

N. Y., on May 9, 1945, under the auspices of the ASA. Interest was shown in this project, and a statement is being prepared setting forth the practices in this country.

(4) An international definition of the term "rayon"—suggested by the New York Board of Trade: In the United States, the term "rayon" is limited to textile fiber or yarn produced chemically from cellulose or with a cellulose base. In England the term is not so limited. The ASA Advisory Committee on Ultimate Consumer Goods to whom the subject had been referred for advice is recommending that the definition be discussed internationally.

(5) Unification of the methods of testing textiles used in different countries—suggested by the National Bureau of Standards: At a recent meeting of the Sectional Committee on Fastness of Colored Textiles (ASA Project L14) it was decided to recommend that such international discussions be initiated. The question as to what methods in use in this country should serve as the basis for these international discussions was referred to a special committee under the chairmanship of W. D. Appel, on which A.S.T.M. is represented by J. Robert Bonnar.

(6) Standardization of terms used in the plastic industry—suggested by the British Standards Institution: At a recent meeting of the American Advisory Committee on UNSCC, this matter was laid on the table at least until further information is obtained from the London office from which the proposal emanated.

Committee E-10 will give consideration to proposals relating to participation by A.S.T.M. in standardization projects of the UNSCC and will present periodic reports to the Executive Committee of the Society on the developments in such projects.

Respectfully submitted on behalf of the committee,

H. S. VASSAR,
Chairman.

R. E. HESS,
Ex-officio Secretary.

TECHNICAL PAPERS

With Discussions

FRACTURE TESTING OF ALLOY STEELS FOR AIRCRAFT ENGINE FORGINGS

By R. D. Haworth, Jr.[1] and A. F. Christian[1]

Synopsis

An unusual condition of alloy-steel forgings, shown by fracture examination and termed "grain coarsening," has attracted considerable interest in recent years among the manufacturers of highly stressed aircraft engine parts. The appearance of large grains or "facets" on the fractured surface of fully heat-treated forgings was generally considered indicative of overheating during the forging operation. However, it has been clearly demonstrated that this condition can be produced in certain heats of steel at normal forging temperatures. Other factors equally as influential as heat sensitivity are: (1) the time at temperature, and (2) the amount of reduction during the forging operation.

While a small amount of grain coarsening has no harmful effect on physical properties, a larger amount decreases toughness, and hence the condition should be eliminated from aircraft engine members as far as possible. The fracture test was proposed and adopted as the most satisfactory and sensitive means of accomplishing this end.

In conjunction with careful material acceptance testing and accurate hardness surveys, the fracture test can be used to replace the conventional tension and impact tests with equal reliability and considerable saving in material, time, effort, and expense.

In this report, photographs of fractures after various heat treatments are shown and a complete set of fracture test standards are presented. Operation of the test in production is described as well as the results which have already been achieved. A study of the present state of knowledge concerning the cause and mechanism of grain coarsening is also submitted.

The occasional presence of large grayish grains or "facets" against the normally entirely fibrous fracture of fully heat-treated alloy steel has caused considerable concern among aircraft engine manufacturers in recent years. The condition was at first associated with overheating (the use of excessively high temperatures during the forging operation) because it could be most readily reproduced experimentally by heating the steel above the maximum recommended forging temperatures. However, as later discovered after the establishment of exacting temperature control in uniformly heated furnaces, the same condition may be produced at normal forging temperatures on certain heats of steel, particularly if delay time is necessitated in the forge furnace for hammer repairs. The condition, therefore, is a function of four variables: the susceptibility of the steel, the forging temperature, the time at temperature, and the amount of mechanical work after heating. Since the term "overheating" has an unsavory flavor bespeaking as it does of poor forging practice, its use will be restricted in this discussion to the very bad fractures which can be produced only by heating to excessive temperatures. For less severe fractures, principally typical of those which can and have been produced at normal forging temperatures, the abnormal fracture condition will be referred to as "grain coarsening" (or simply as "coarsening"). The origin of this expression stems from the belief that the facets are "ghosts" of the coarse grains which existed at the forging temperature. Normal forging temperatures are established as low as possible consistent with an adequate rate of production and upkeep of hammer equipment.

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[1] Metallurgist and Chief Metallurgist, respectively, Wyman-Gordon Co., Ingalls-Shepard Div., Harvey, Ill.

Apprehension regarding the unusual fracture appearance arose because of the known adverse effect of severe overheating on toughness and ductility which in the past has contributed to premature failures in service. Tensile strength and yield strength are unaffected even by severe overheating, but ductility suffers a gradual decline as the extent of grain coarsening increases. These observations led to consideration of the fracture test as a useful metallurgical test to eliminate steel with the type of fracture correlative to borderline or sub-standard physical properties. The fracture test can be made to cover a larger area of the forging than the standard physical tests and hence can be a more representative and comprehensive test.

The fracture test is an old, useful, and well-known test on steel for the purpose of detecting internal defects (such as flakes, bursts, pipe, and heavy nonmetallic inclusions or segregation) and for determining fracture grain size and hardness penetration.[2] However, no references to grain coarsening obtained at normal forging temperatures have been noted in the literature although the completely coarsened fracture appearance of steel which has been severely overheated is undoubtedly well known. Jominy[3] investigated the maximum temperatures to which various carbon and low-alloy steels can be heated without burning or permanently damaging the normal physical properties of the material after subsequent heat treatment. He shows coarse grains in some of his tensile specimens but only on those which have been heated to temperatures far in excess of the maximum recommended forging temperatures.

The usefulness of the fracture test is not confined to the detection of grain coarsening alone. On thorough hardening steels, such as S.A.E. 4340, which are fully heat treated to final hardness before rough machining, the fracture appearance will indicate whether the parts have been correctly heat treated. When correlated with careful material acceptance testing and accurate Brinell hardness surveys (which bear a fixed relationship to tensile strength up to a hardness of approximately 450 Brinell), the test is as reliable as the standard tension and impact tests and can be used to replace these tests. The expense of machining test specimens is eliminated and since smaller test prolongations can be used than for the conventional tests, an important saving in alloy steel is effected.

As the fracture test is made and interpreted directly on the forgings, another important advantage over the standard tests is achieved; that is, serial numbering of the corresponding test specimens and forgings is unnecessary. A simple temporary numbering system is used for the relatively few questionable fractures held out on the production line for laboratory review. Sorting and selection of forgings according to serial numbers prior to shipping is avoided as well as voluminous quantities of paper work both for the vendor and engine manufacturer; the only records necessary are the steel heat numbers and chemistry plus certification to the correct Brinell hardness range and satisfactory fracture appearance.

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[2] *A.S.M. Handbook*, "Physical Testing of Tool Steels," Am. Soc. Metals, 1939 Edition, pp. 652–654.

[3] W. E. Jominy, "A Study of Burning and Overheating of Steel—Parts I, II, and III," *Transactions*, Am. Soc. Metals, Vol. 16, pp. 298–313, 372–392, 893–936 (1929).

On forgings which are heat treated for maximum machinability, that is, cycle annealed, normalized, or normalized and drawn, the fracture test on the rough forging serves only to eliminate grain coarsened material as it obviously cannot serve as an indicator of the quality of the final heat treatment of the steel. To be fully reliable for the purpose of eliminating coarsened steel, the fracture test must be made on material in the quenched-and-drawn condition. To satisfy this requirement, a method of locally hardening and drawing the test specimens directly on the forging was developed and will be described in detail. A series of fracture photographs will be described in the following section to demonstrate the importance of fracture testing steel in the quenched-and-drawn state. These fractures were all broken transversely to the direction of grain flow as the transverse fracture is considerably more sensitive for the detection of grain coarsening than the longitudinal fracture (see Section titled "Further Testing").

FRACTURE APPEARANCE VERSUS HEAT TREATMENT

In order to evaluate properly prior forging and heat treating operations, the fracture test should be conducted on fully heat-treated material. In this state, the normal transverse fracture has a characteristic fibrous appearance as shown in Fig. 1(*a*). Grain coarsening produced by certain forge heating and forging conditions is revealed by the presence of flat grayish facets against the fibrous background as in Figs. 2(*a*), 3(*a*), 4(*a*), and 5(*a*). Severe overheating produces three dimensional (euhedral) facets that largely exclude the fibrous fracture as in Fig. 6(*a*).

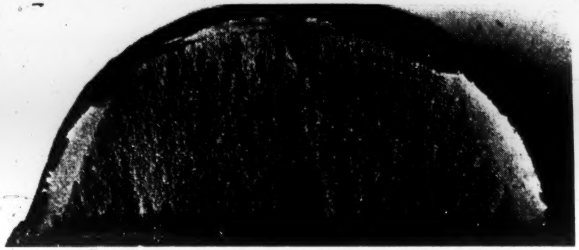
The normal fracture on thorough hardening steels in any other state but quenched and drawn, such as as-forged, normalized, normalized and drawn, or cycle annealed is partly or entirely crystalline. Poorly or incompletely hardened steels will also show a partly crystalline fracture. The appearance of the crystalline fracture is relatively unaffected by the degree of coarsening present so that even badly overheated steel will be partially, if not entirely, disguised.

All fractures shown in this article, including fracture standards, were made on S.A.E. 4340 steel (A.M.S. 6415). However, the fracture standards and most of the discussion on fractures are generally applicable to other alloy steels such as S.A.E. 2515 (A.M.S. 6242) and S.A.E. 3312 (A.M.S. 6250) as well as even plain carbon steels when the section size is small enough to harden to the necessary degree.

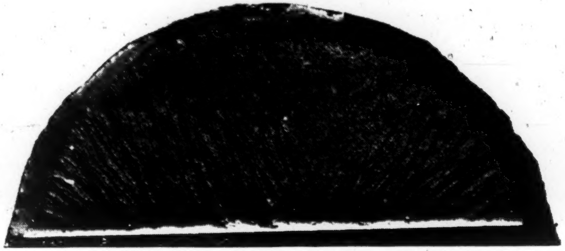
As-Forged and As-Heated Fractures:

The characteristic fracture appearance of normally heated and forged S.A.E. 4340 steel is shown in Fig. 7(*a*) and the corresponding heat-treated fracture in Fig. 7(*b*). The as-forged fracture is finely crystalline and the heat-treated fracture entirely fibrous and free from any traces of grain coarsening. Other examples, however, have been noted where the as-forged fracture has been even finer than in Fig. 7(*a*) but where the quenched-and-drawn fracture has shown severe overheating with correspondingly low physical properties.

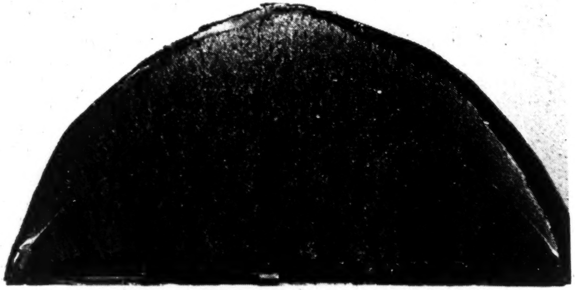
If steel is fractured after heating to the forging temperature without subse-



(*a*) Quenched and drawn to 363 maximum Brinell.



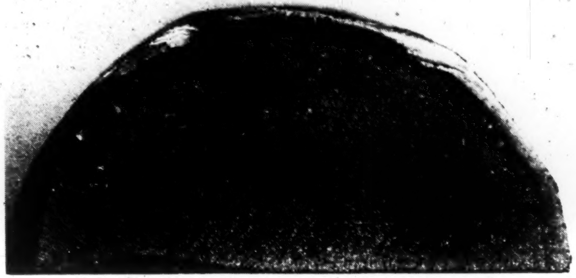
(*b*) Normalized, quenched, and drawn to 415 Brinell.



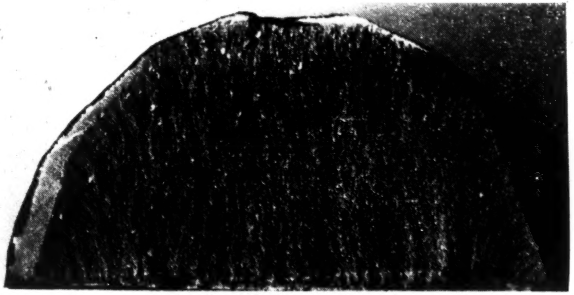
(*c*) Normalized, quenched, and drawn to 321 Brinell.

Fig. 1.—Acceptable on Production Line—Normal Fracture Natural size.

(*a*) Quenched and drawn to 363 maximum Brinell.

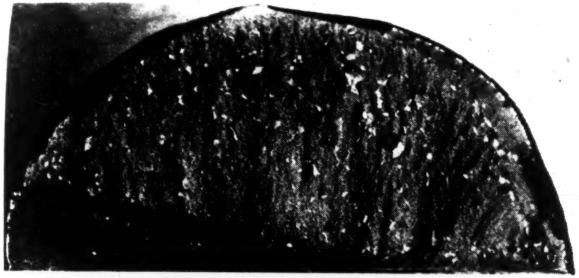


(*b*) Normalized, quenched, and drawn to 415 Brinell.

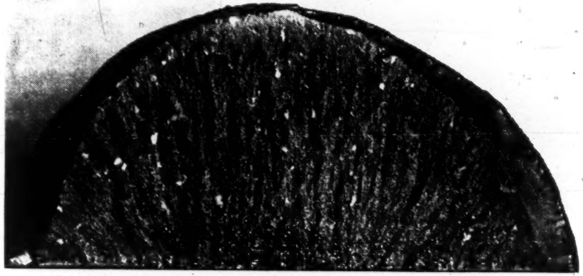


(*c*) Normalized, quenched, and drawn to 321 Brinell.

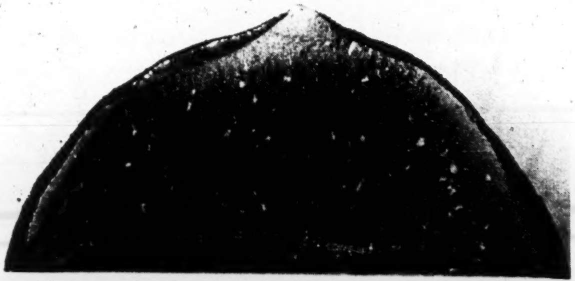
Fig. 2.—Acceptable on Production Line—Trace.



(*a*) Quenched and drawn to 363 maximum Brinell.

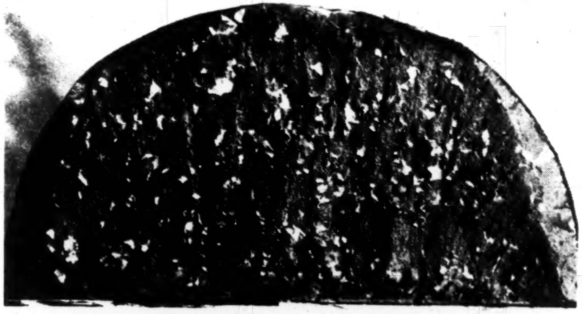


(*b*) Normalized, quenched, and drawn to 401 Brinell.

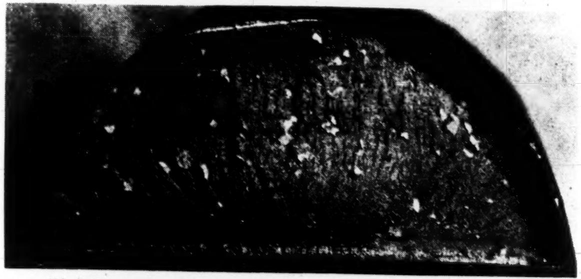


(*c*) Normalized, quenched, and drawn to 321 Brinell.

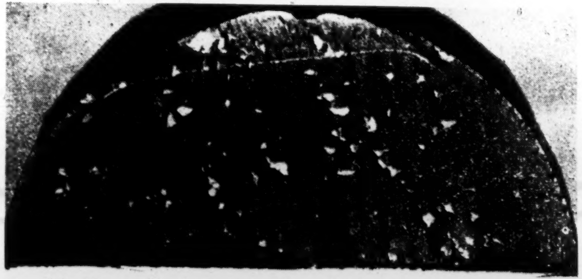
FIG. 3.—Subject to Metallurgical Review—Mild—Acceptable.



(*a*) Quenched and drawn to 363 maximum Brinell.

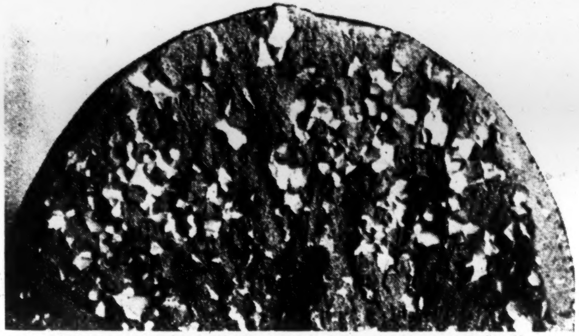


(*b*) Normalized, quenched, and drawn to 401 Brinell.

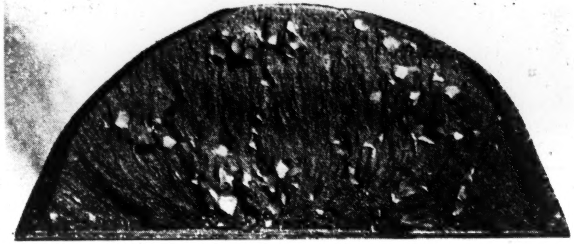


(*c*) Normalized, quenched, and drawn to 331 Brinell.

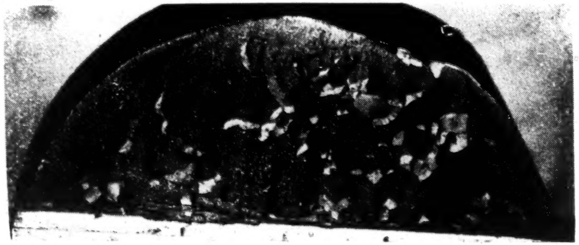
FIG. 4.—Subject to Metallurgical Review—Further Tests Required.



(*a*) Quenched and drawn to 363 maximum Brinell.

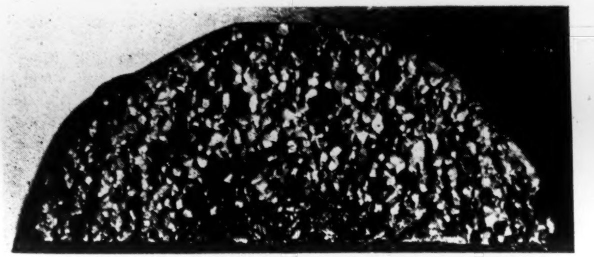


(*b*) Normalized, quenched, and drawn to 401 Brinell.

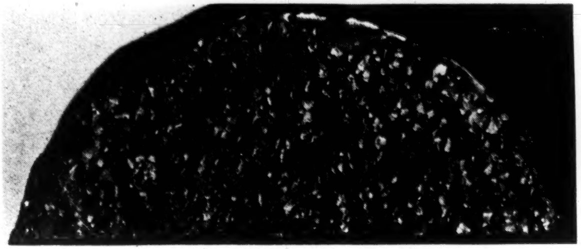


(*c*) Normalized, quenched, and drawn to 321 Brinell.

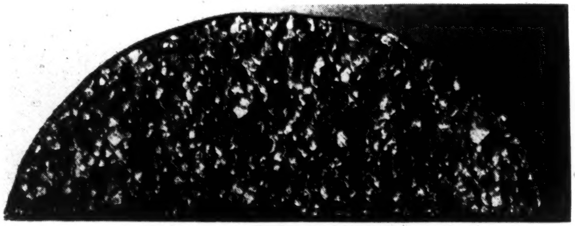
FIG. 5.—Subject to Metallurgical Review—Bad—Not Acceptable.



(*a*) Flame hardened and drawn to 363 maximum Brinell.



(*b*) Normalized, quenched, and drawn to 415 Brinell.

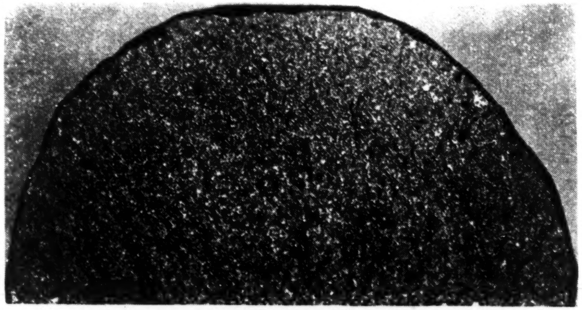


(*c*) Normalized, quenched, and drawn to 331 Brinell.

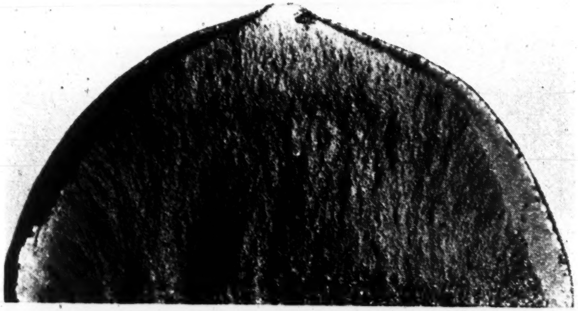
FIG. 6.—Subject to Metallurgical Review—Very Bad—Not Acceptable.

(*c*) Normalized, quenched, and drawn to 321 Brinell.
FIG. 5.—Subject to Metallurgical Review—Bad—Not Acceptable.

FIG. 6.—Subject to Metallurgical Review—Very Bad—Not Acceptable.

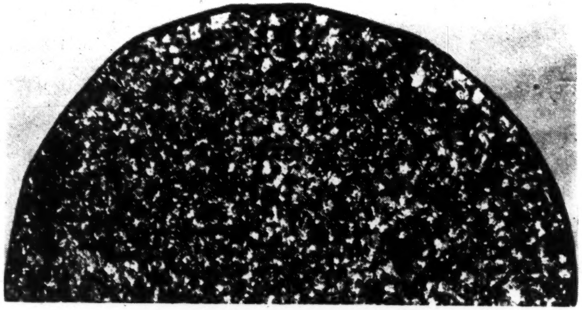


(*a*) As forged and air cooled.



(*b*) Quenched and drawn to 321 Brinell.

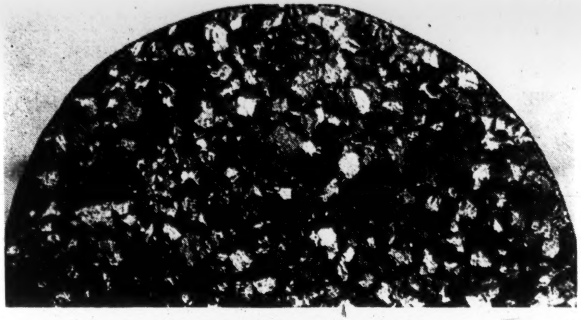
FIG. 7.—As Forged at 2100 F. from $3\frac{1}{2}$ in. Round to 3 in. Round and Air Cooled.



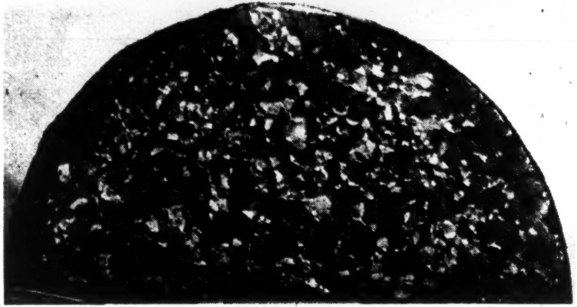
(*a*) As heated and air cooled.

(*b*) Quenched and drawn to 321 Brinell.

FIG. 8.—As Heated to 2350 F. and Air Cooled.

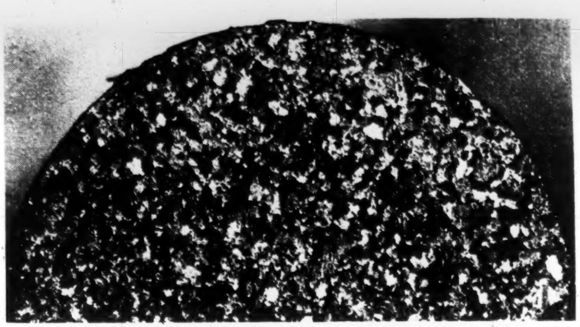


(*a*) As heated and air cooled.

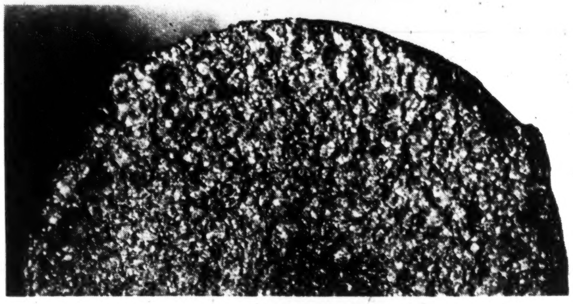


(*b*) Quenched and drawn to 321 Brinell.

FIG. 9.—As Heated to 2460 F. and Air Cooled.

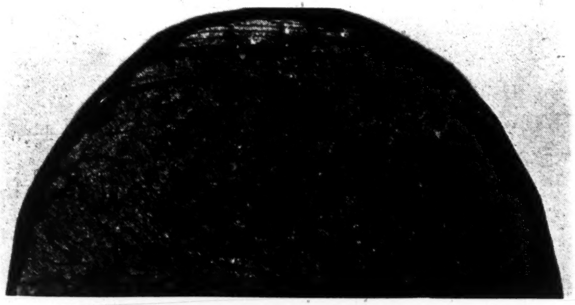


(*a*) As heated and air cooled.

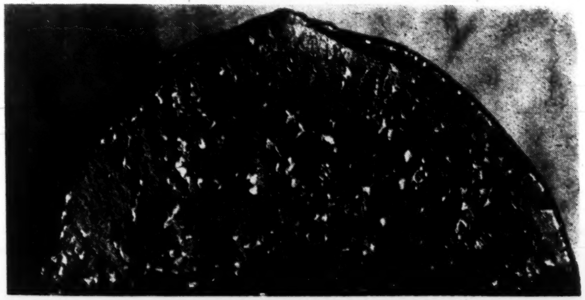


(*b*) Quenched and drawn to 321 Brinell.

FIG. 10.—As Heated to 2600 F. and Air Cooled.

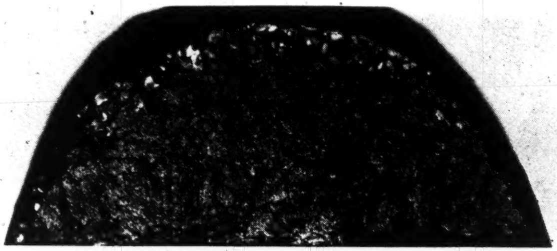


(*a*) Normalized and drawn.

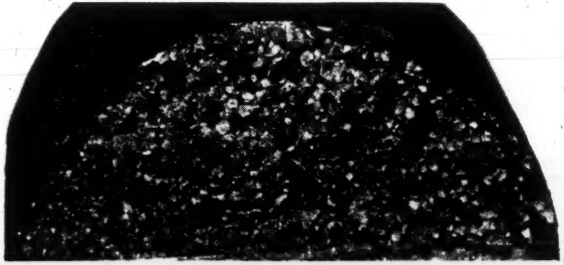


(*b*) Quenched and drawn to 321 Brinell.

FIG. 11.—Normalized and Drawn at 1250 F.

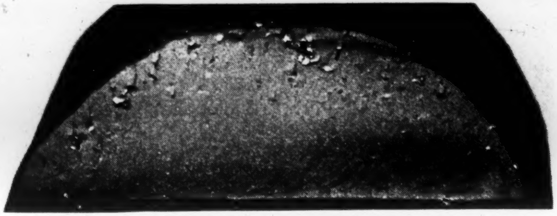


(*a*) Normalized and drawn.

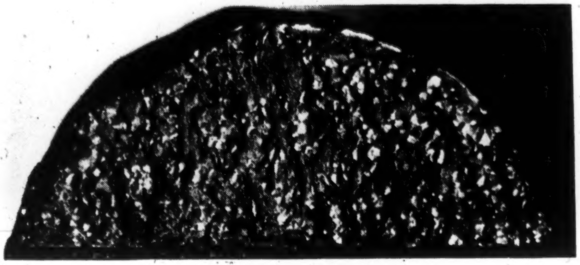


(*b*) Quenched and drawn to 321 Brinell.

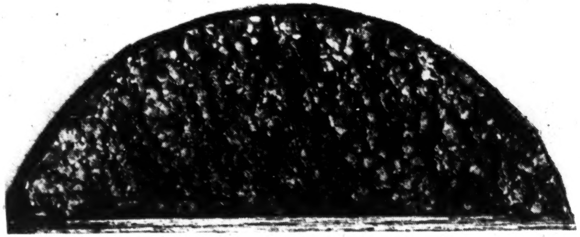
FIG. 12.—Normalized and Drawn at 1250 F.



(*a*) Not drawn, 495 Brinell.

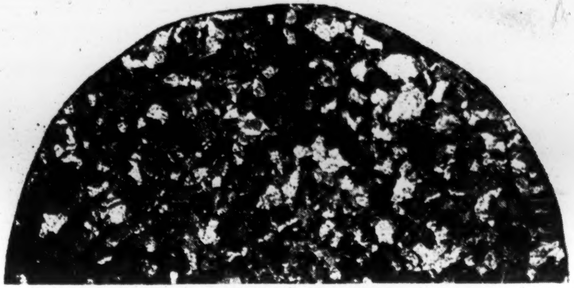


(*b*) Drawn to 415 Brinell.

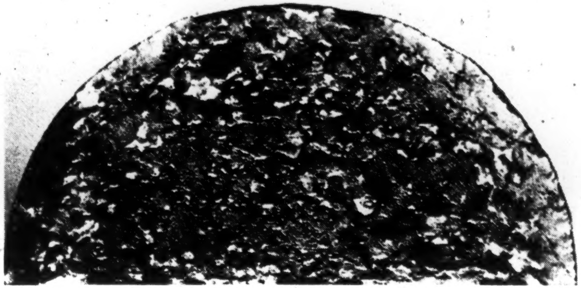


(*c*) Drawn to 341 Brinell.

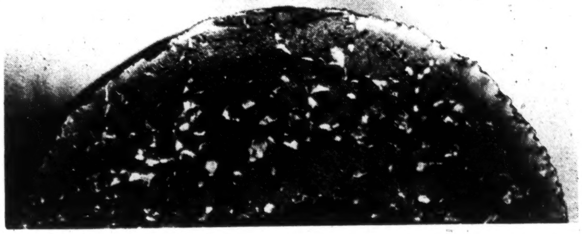
FIG. 13.—Effect of Hardness on Oil Quenched and Drawn Fractures.



(*a*) Green stock, broken at room temperature.



(*b*) Green stock, broken "hot" (450 F.).



(*c*) Quenched and drawn, broken at room temperature.

FIG. 14.—Effect of Breaking Temperature.

quent forging, more coarsely crystalline fractures are obtained. Figure 8(*a*) shows the fracture from a bar of steel heated to 2350 F. and air cooled; Fig. 9(*a*) shows another bar from the same heat of steel heated to 2460 F. and likewise air cooled without forging. The corresponding heat-treated fractures are shown in Figs. 8(*b*) and 9(*b*), respectively. For individual heats, the as-heated fracture grain size is proportional to the degree of grain coarsening and could be used as a crude criterion of such. This is not true, however, for different heats of steel (see Figs 10(*a*) and 10(*b*)). Figure 10(*a*) is a fracture from a different heat of steel than in Figs. 8(*a*) and 9(*a*). The as-heated fracture grain size is similar to that in Fig. 8(*a*) and considerably finer than in Fig. 9(*a*); yet the fracture in Fig. 10(*b*) is worse than in either Figs. 8(*b*) or 9(*b*) and is indicative of steel which was very badly overheated if not burned.

Normalized and Drawn:

Since this discussion is concerned primarily with S.A.E. 4340 type steel, no as-normalized fractures will be shown because in normal aircraft practice the steel is never machined or used in this condition. Sluggish transformation usually causes the formation of some hard constituents, and, therefore, satisfactory machinability cannot be achieved unless the steel is drawn at a high temperature after normalizing. However, the only difference between as-normalized and normalized-and-drawn fractures is that the normalized fracture is invariably entirely crystalline, whereas the normalized-and-drawn fracture shows varying degrees of fibrous and crystalline fracture usually in alternating bands. If a large amount of fibrous fracture is exposed, a fair picture of the presence or absence of grain coarsening can be obtained. If, however, the fracture is almost all crystalline as in Figs. 11(*a*) and 12(*a*), then even severe overheating might not be noticed. The corresponding heat-treated fractures shown in Figs. 11(*b*) and 12(*b*) illustrate that, although the normalized-and-drawn fractures may be similar in appearance, a vast difference may exist in the fracture and corresponding physical properties after a quench and draw.

Cycle Annealed:

No photographs of cycle annealed fractures will be shown because the fractures are almost identical in appearance and in the amount of variation of fibrous and crystalline structure as in the case of normalized-and-drawn fractures.

As-Quenched—Effect of Draw Temperature:

Because the Shepherd "P-F" fracture test[4] is made in the as-quenched condition, the tendency might prevail on the part of the uninitiated to assume that the as-quenched fracture would be the most sensitive for detecting grain coarsening. Actually, even very severe overheating will be largely, if not entirely, obscured, by an as-quenched fracture. Figure 13(*a*) shows the fracture of a severely overheated steel in the as-quenched condition. This shows but slight evidence of the degree of grain coarsening actually present as indicated in Figs. 13(*b*) and 13(*c*). These latter figures also illustrate the effect of drawing temperature and the resultant Brinell hardness on the extent of the grain coarsening revealed.

APPLICATION OF THE FRACTURE TEST IN PRODUCTION

The fracture testing of forgings which are fully heat treated (normalized, quenched, and drawn) to the final hardness before rough machining is a simple matter. The test specimen which is forged integrally with the part is merely notched and broken and the fracture examined; if the fracture is satisfactory and the Brinell hardness values are within the required range, the forging is suitable for shipment. As an additional check on the reliability of parts passed by fracture examination, a tension test is made from one forging out of every 500 or one from each heat of steel, whichever is the smaller.

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[4] B. F. Shepherd, "The P-F Characteristics of Steel," *Transactions*, Am. Soc. Metals, Vol. 22, p. 979 (1934).

One note of caution in fracture testing is deemed advisable at this point; namely, the importance of breaking the fracture of fully heat-treated parts at room temperature. If the fracture test specimen is heated above 250 F. in the notching operation (which can easily happen if an abrasive cut-off wheel is used), a normal fibrous fracture, identical to that obtained on fully heat-treated material, will be obtained on as-forged or as-normalized material. Overheating would be detected but improperly heat-treated material would not be eliminated. This peculiarity of the fracture (which will be referred to as the "hot" fracture) is illustrated in Fig. 14. The fracture of S.A.E. 4340 steel heated to 2400 F. for 4 hr. and then broken at room temperature is shown in Fig. 14(*a*). The same specimen broken at 450 F. (Fig. 14(*b*)) shows a fibrous fracture previously considered typical only of quenched and drawn material. Facets indicative of grain coarsening are plainly visible. The same piece when quenched and drawn and broken at room temperature shows a similar but somewhat less fibrous fracture (see Fig. 14(*c*)). The reason for the change in the nature of the fracture is readily explainable. Impact values obtained on the as-heated steel at a series of temperatures up to and including 550 F. increased from 8 ft-lb. at room temperature to 33 ft-lb. at 550 F. Since the tensile strength of S.A.E. 4340 steel over this same range suffers a small decrease in value, the resistance to shear type or brittle failure increases greatly (as illustrated by the increase in impact values) while the resistance to tensile failure decreases slightly. Since the resistance to shear increases as the resistance to tensile failure decreases, fibrous type fractures eventually result as the breaking temperature is increased.

Many parts made of S.A.E. 4340 are only normalized and drawn or cycle annealed before rough machining. On these parts, in order to determine the true extent of grain coarsening, some method of local hardening and drawing the test specimen to obtain fibrous fractures had to be devised. It would be impractical, if not impossible, to carry the fracture test section or prolongation through the rough machining operations and then make the fracture test after final heat treatment. In the past when such parts, now fracture tested, were tested in tension, the test specimens were assigned serial numbers corresponding to the forging from which they were cut at some stage in the rough machining operation. The test specimens were then quenched and drawn along with the rough machined part. The same procedure could be followed with the fracture test specimen or the fracture specimen could be cut from the forging at the vendor's plant and furnace treated in batch lots. This latter method was temporarily used when the fracture test was first inaugurated on non-heat-treated forgings but had three serious disadvantages:

1. Serial numbering of all forgings and test prolongs was required.
2. In most cases the test specimens were small in order to conserve material so that only a longitudinal fracture could be obtained.
3. Loose test specimens were frequently lost or misplaced, causing the loss of good forgings.

Several methods of locally hardening and drawing the fracture test specimens were investigated. The most practical means of accomplishing this objective was found to be by flame heating with a single row, multi-flame, oxygen-acetylene burner. The fracture test portion is notched with a mechanical hacksaw leaving about $\frac{3}{8}$ to $\frac{3}{4}$ in. for fracturing depending on the size of the forging. The uncut portion is rapidly heated above the critical temperature with the flame head at a sufficient distance from the surface to avoid excessive heating. After quenching, using an air blast for S.A.E. 4340 steel in order to prevent quench cracking, the hardened zone is drawn back to approximately 1100 to 1200 F. using a similar flame head but with a smaller flame and situated at a greater distance from the forging. The test specimen is then cooled from the draw heat with a water spray and immediately broken off with a mechanical press. A study of the flame hardening process used will be presented later.

FIG. 15.—Fracture Test Specimen.

A typical flame-hardened fracture test specimen used on large crankshafts is shown in Fig. 15. The flame hardening table, which rotates in a clockwise direction, for progressively hardening and

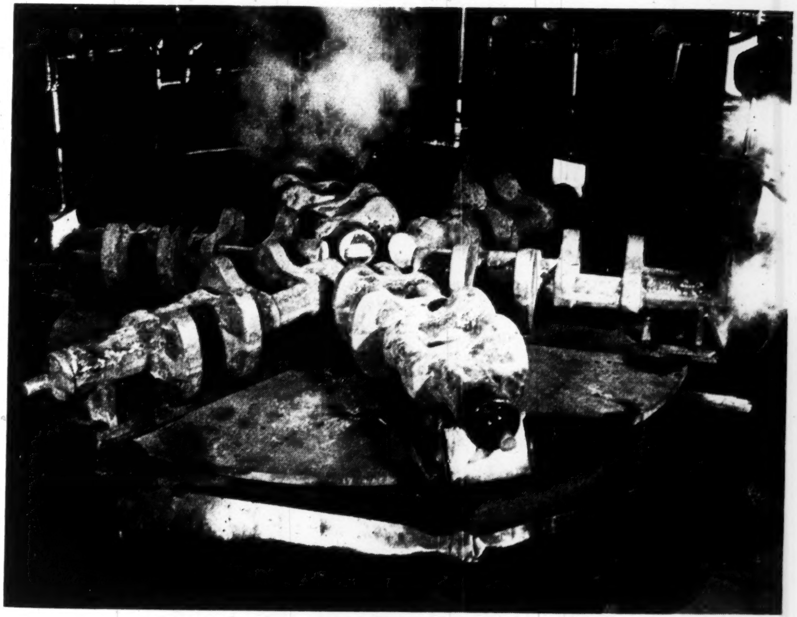


FIG. 16.—Flame Hardening Table.

drawing this type of crankshaft is shown in Fig. 16. Figure 17 shows a fracture test specimen being broken off in a mechanical press.

It might be considered that hot fracturing could be used for producing fibrous fractures but investigation has shown that there are disadvantages that eliminate its practical application. On green stock poor correlation was obtained between certain hot fractured specimens and corresponding heat-treated fractures. On normalized and drawn or cycle annealed stock satisfactory correlation to heat-treated specimens was obtained but difficulty was experienced in breaking off the fracture specimens because of the excellent ductility of the material. Three strokes of the press were required to effect removal instead of a single stroke as on flame hardened and drawn test specimens.

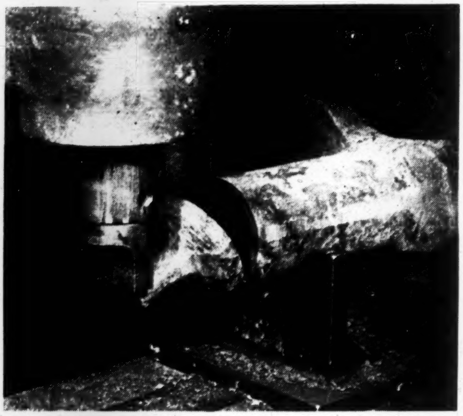


FIG. 17.—Fracture Test Press.

It has been previously pointed out that on parts which are not fully heat treated before rough machining the fracture test cannot serve as an indicator of the quality of the final heat treatment but is useful in eliminating coarsened forgings, thus avoiding useless, expensive machining operations. Compliance with the basic physical specifications after heat treatment is assured by proper steel acceptance testing, careful hardness checks on the finished part, and a representative tension test on a coupon furnished from the same heat of steel.

FRACTURE STANDARDS

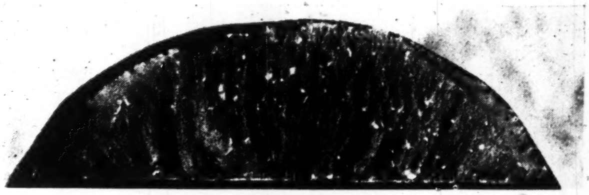
Since all forgings cannot be produced consistently free of some degree of grain coarsening, at the present time, the establishment of fracture standards based on physical property data is required. Proposed fracture standards are shown in Figs. 1(*a*) to 6(*c*), inclusive. Corresponding physical properties, which in the milder cases have been fully substantiated on production forgings, are shown in Table I. Experience has shown that three sets of standards are advisable:

(*a*) Flame hardened and drawn (quenched and drawn only)

(*b*) Fully heat treated to high Brinell range (approximately 375 to 429 BHN)

(*c*) Fully heat treated to low Brinell range (approximately 269 to 363 BHN)

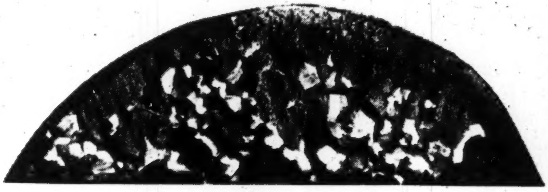
Two sets of standards on fully heat-treated material are required because the sensitivity of the fracture test is dependent on the extent the material is drawn after hardening. The ideal fracture on S.A.E. 4340 steel is a tough fibrous structure obtained in the Brinell range of 269 to 363. Above a Brinell hardness of approximately 363, the fracture becomes gradually less fibrous and more silky and its sensitivity for the detection of grain coarsening is lessened (compare Figs. 5(*b*) and 5(*c*)). The as-quenched fracture is entirely silky and only very severe overheating can be detected. Fortunately up to and including a Brinell hardness of 429 (the maximum hardness used for S.A.E. 4340 steel in commercial production), the fracture is sufficiently sensitive to eliminate the degree of grain coarsening which would adversely affect physical properties. The decision of which set of standards to use for a given part depends on the hardness range specified for the part. If the range for a part should overlap the fracture standard hardness ranges, then the decision would depend on the background appearance of the fracture. That is, if the fracture is fibrous, the standards for the lower hardness range would apply; if between a fibrous and silky fracture, the higher hardness range.



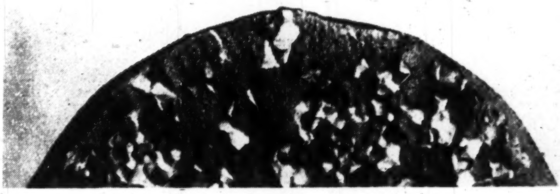
(*a*) Flame hardened and drawn.

(*b*) Furnace hardened and drawn.

FIG. 18.—Comparison of Flame and Furnace Hardening—Mildly Coarsened.



(*a*) Flame hardened and drawn.



(*b*) Furnace hardened and drawn.

FIG. 19.—Comparison of Flame and Furnace Hardening—Badly Coarsened.

On forgings that are not fully heat treated before machining, the flame hardened and drawn fracture is obtained on green stock (as-forged). If the operation were carried out after the normalize-and-draw or cycle anneal treatments, hard spots would be left on the forging unless a subsequent drawing operation were employed after the fractures were broken. Such extra operations are, of course, undesirable on a production line.

The flame-hardened fracture made on green stock does not have the benefit of the normalizing treatment which causes a marked refinement in the fracture of fully heat-treated steel. The value of the normalizing treatment can be fully appreciated by comparing a quenched-and-drawn fracture of mildly coarsened steel obtained on green stock with the same piece of steel fractured after normalizing, quenching, and drawing to the same hardness (compare Figs. 4(*a*) and 4(*c*)). The facets in the fully treated fractures are always dull and grayish-white while those in the flame-hardened fracture are frequently shiny and metallic in appearance. Apparently some type of action has taken place during the normalizing causing a change in the facet appearance and reducing the size and number of facets. Since the flame-hardened fracture on green stock is overly sensitive, fracture standards for flame-hardened forgings must be more liberal than for forgings fracture tested after full heat treatment. In this way material which would have a satisfactory fracture appearance after full heat treatment will not needlessly be rejected.

TABLE I.—PHYSICAL PROPERTIES MATERIAL NORMALIZED, QUENCHED, AND DRAWN

	Minimum Requirement	Group 1 Normal	Group 2 Trace	Group 3 Mild	Group 4 Further Tests	Group 5 Bad	Group 6 Very Bad
High Hardness Range							
Tensile strength, psi.	185 000	202 000	203 000	198 750	198 000	198 500	205 750
Yield point, psi.	170 000	195 500	192 000	188 250	189 250	191 250	202 000
Elongation, per cent	10.0	12.5	12.0	13.0	12.0	11.5	4.0
Reduction of area, per cent	30.0	45.8	42.5	43.0	37.3	36.4	8.5
Izod impact, ft-lb.	.....	21	19	22	24	22	9
Brinell hardness number	375–430	415	415	401	401	401	415
Endurance limit, psi.[a]	.....	82 000	.....	.....	80 000	.....	49 000
Low Hardness Range							
Tensile strength, psi.	140 000	151 500	154 000	154 000	163 000	152 250	159 800
Yield point, psi.	120 000	135 000	135 500	142 000	153 000	135 000	149 200
Elongation, per cent	15.0	18.0	18.5	19.0	17.5	16.0	8.5
Reduction of area, per cent	50.0	57.9	54.4	55.3	50.0	46.2	10.5
Izod impact, ft-lb.	35	70	65	58	51	48	28
Brinell hardness number	302–341	321	321	321	331	321	331
Endurance limit, psi.[a]	.....	70 000	.....	.....	72 500	71 000	55 000

[a] Made using an R. R. Moore machine with an ⅛-in. radius groove specimen (stress concentration factor about 1.2) rather than the standard 10-in. radius specimen.

Flame-hardened-and-drawn fractures can be duplicated in appearance by furnace-heated, quenched-and-drawn fractures as shown in Figs. 18(*a*), 18(*b*), 19(*a*) and 19(*b*). In preparing the fracture standards, it was considered advisable to show fracture areas larger than could be conveniently obtained by flame hardening. Uniform results on flame-hardened fractures on depths of more than ¾ in. are difficult to obtain. For this reason, furnace-hardened, rather than flame-hardened, fractures, with the exception of Fig. 6(*a*), were used in the fracture standards.

Fractures corresponding to the photographs shown in groups 1 and 2 may be passed as acceptable by the inspectors on the production line. Fractures comparable to those in groups 3 and 4 are held out for laboratory review. Those in group 3 may be passed without further tests by decision of a competent metallurgist. Group 4 fractures require additional testing which will be covered in the next section. Forgings showing the type of fracture illustrated in Figs. 5 and 6 would be scrapped immediately, and the fracture coupon sent to the laboratory for further investigation. This grouping is substantiated by the physical properties, shown in Table I, which were determined on the identical coupons used for the fracture illustrations. Yield and tensile strengths are not affected even by very severe overheating, and fatigue properties suffer diminution in value only when the overheating is very severe (group 6). Ductility and toughness (impact) gradually decline as the degree of coarsening increases but are still above the minimum requirement in all groups except the low Brinell range of group 5, and decline drastically only in group 6.

Although the basic concept of the fracture testing program is to provide a simpler means of testing yet comparable in reliability to the conventional physical tests in eliminating material which will not pass the minimum required physical properties, the standards were not established wholly on that basis alone. The fractures were classified into two main groups: those acceptable on the production line which are entirely free from any evidence of grain coarsening or contain only a trace; and those which contain evidence of mild overheating or are definitely bad. If the standards were established strictly on the basis of physical properties, group 4 would be acceptable without question and group 5 would then be borderline and subject to further tests. However, because an important objective of fracture testing is to secure an overall improvement in forging quality by minimizing grain coarsening, standards were established more stringently on the basis of appearance than would actually be required on the basis of corresponding physical properties.

FURTHER TESTING—LONGITUDINAL FRACTURES

If forgings are found with fractures similar to those in group 4, the forging from each heat showing the worst fracture would be fully heat treated (in case of flame-hardened test piece forgings only) and tension and fracture tests taken from appropriate locations throughout the forging. If the properties and additional fractures are satisfactory, all of the other forgings of the group would be approved.

The original specification in effect on fracture testing of forgings required the complete absence of facets on fully heat-treated longitudinal fractures. The longitudinal fracture was used because at the inception of the fracture testing program the flame hardening process for hardening and breaking the fracture section directly on the forging had not yet been developed. The longitudinal fracture which is made parallel to the forging flow lines is considerably less sensitive than the transverse fracture broken across the grain flow. The longitudinal fracture will not reveal a condition of mild grain coarsening which has only a slight effect on physical properties but will reveal more serious coarsening that causes a decrease in ductility to a value approaching the minimum requirement.

Figures 20 and 21 show longitudinal fractures taken from the same pieces as the transverse fracture standards in Figs. 4(*b*) and 4(*c*). The longitudinal fractures show no facets and hence material in the condition shown by the transverse fracture will fully pass the existing requirement. Figures 22 and 23, taken from the same pieces as the transverse fractures in Figs. 5(*b*) and 5(*c*) which are not acceptable, clearly show facets on longitudinal fractures. The lesser sensitivity of the longitudinal test might make it seem more desirable than the transverse because less personal element would be required in judging fractures; if no facets are visible the material is acceptable; if even a few facets

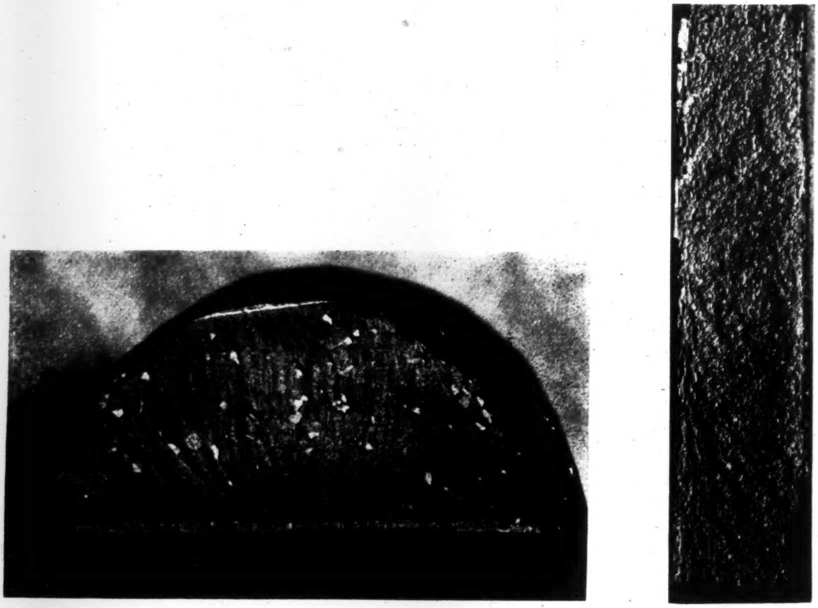


FIG. 20.—Borderline Acceptable.

Comparison of Normalized, Quenched, and Drawn (401 Brinell) Transverse Fracture (Fig. 4(*b*)) and Longitudinal Fracture.

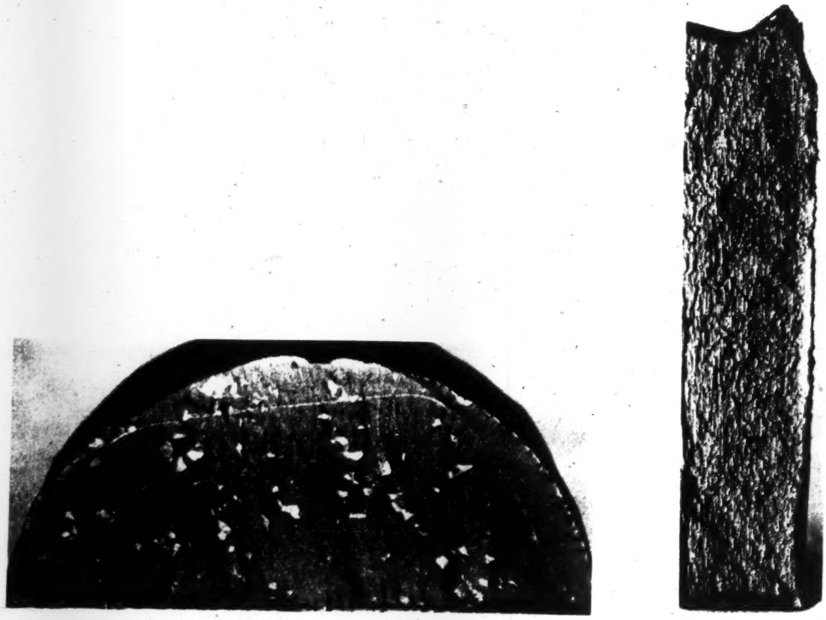


FIG. 21.—Borderline Acceptable.

Comparison of Normalized, Quenched, and Drawn (331 Brinell) Transverse Fracture (Fig. 4(*c*)) and Longitudinal Fracture.

are visible it is rejectable. It is this lesser sensitivity, however, that makes the longitudinal test undesirable because it does not lead to a sufficient improvement in forging quality. Group 4 fractures should be entirely eliminated, if possible, and group 3 minimized as much as possible. Progress toward reaching these goals can only be achieved if the steel is fractured transversely.

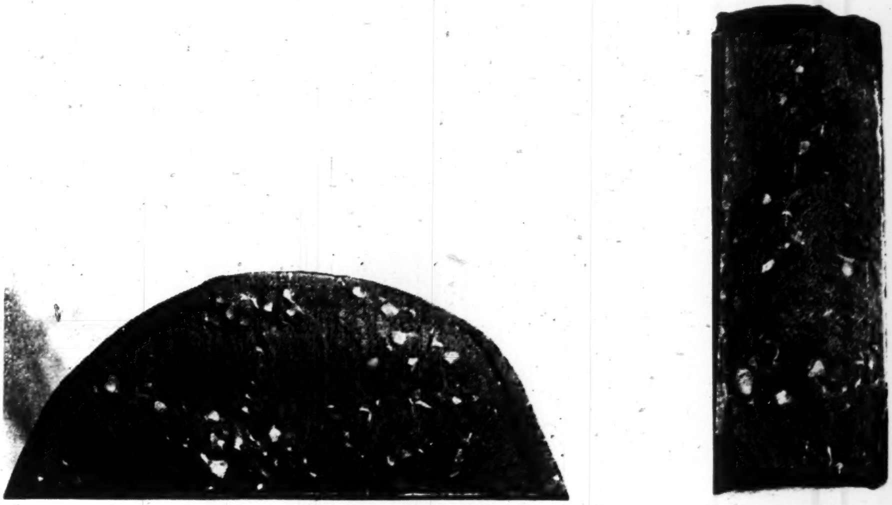


FIG. 22.—Not Acceptable.

Comparison of Normalized, Quenched, and Drawn (401 Brinell) Transverse Fracture (Fig. 5(*b*)) and Longitudinal Fracture.

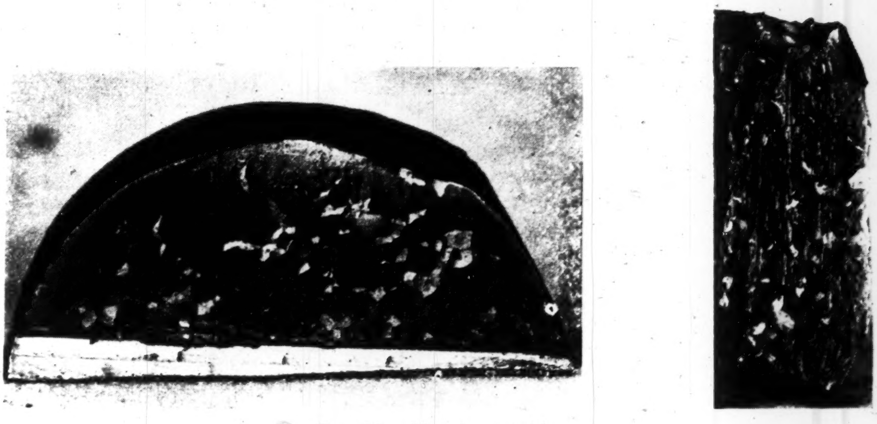


FIG. 23.—Not Acceptable.

Comparison of Normalized, Quenched, and Drawn (321 Brinell) Transverse Fracture (Fig. 5(*c*)) and Longitudinal Fracture.

When steel is overheated as severely as in group 6, the longitudinal fracture is essentially indistinguishable from the transverse (see Fig. 24). Apparently in grain coarsened or mildly overheated steel, the cohesive strength between the

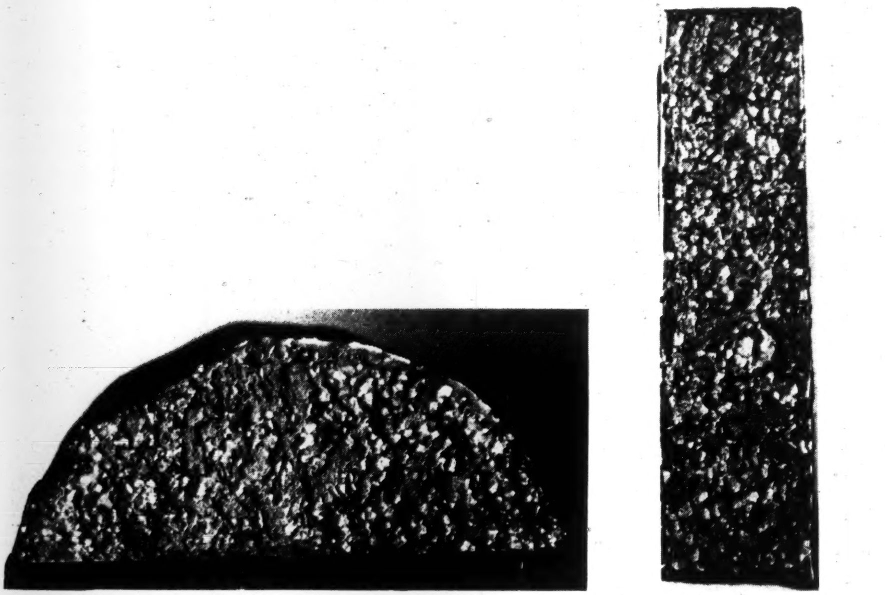


FIG. 24.—Very Bad Fracture.

Badly Overheated. Longitudinal Fracture Is Comparable to Transverse Fracture.—Normalized, Quenched, and Drawn to 415 Brinell.

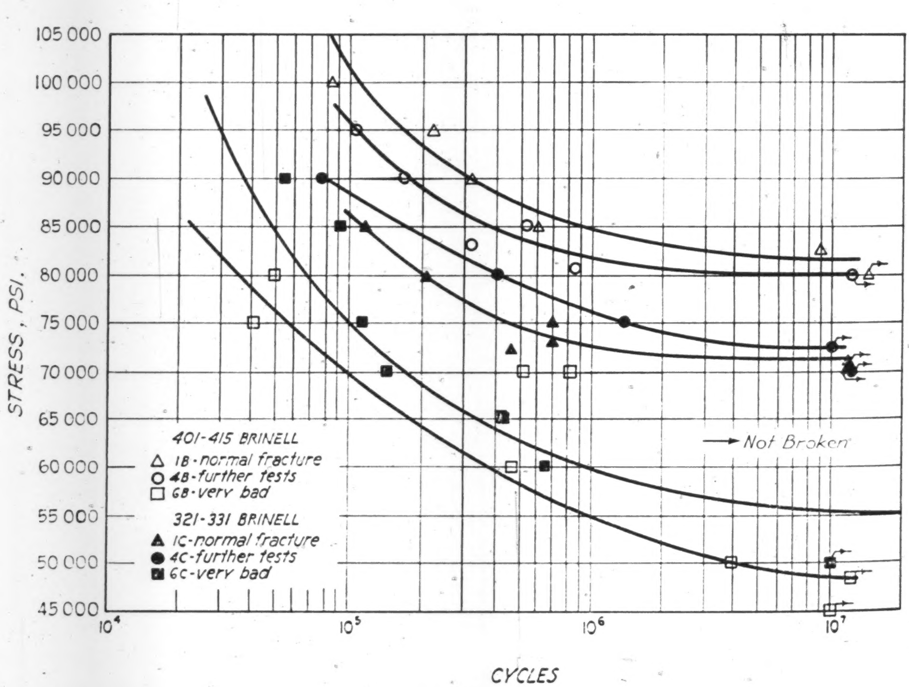


FIG. 25.—Fatigue Tests of Coarsened Material R. R. Moore Specimens 0.230-in. Critical Diameter.

fibers is less than any grain weakening effect produced by the coarsening, and hence no evidence of mild degrees of coarsening which can be seen in the transverse fracture is visible in the longitudinal fracture. This probably also explains why the physical properties decrease only slightly until the degree of overheating is sufficiently severe to appear in the longitudinal fracture.

FATIGUE TESTING

The problem of fatigue failure in aircraft engine parts is one of vital concern.

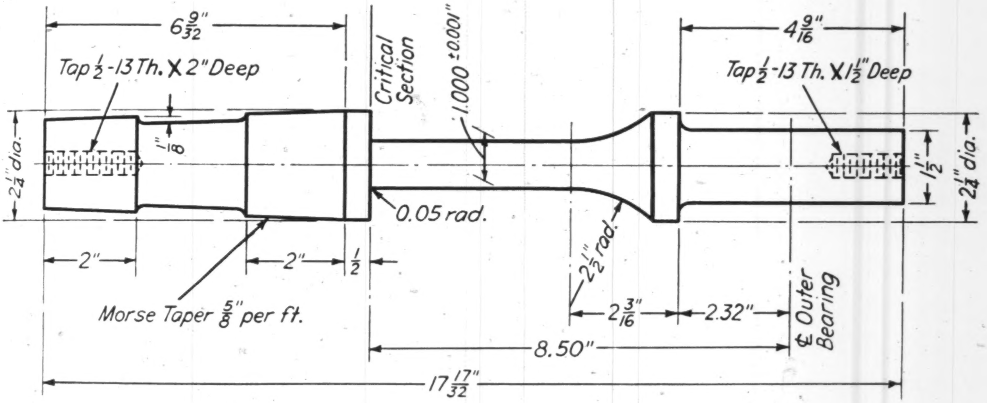


FIG. 26.—Fatigue Test Bar.
Bending Type—1-in. Critical Section With Stress Concentration.

The fact that grain coarsening had only a slight effect on static physical properties was no guarantee that fatigue properties were likewise unaffected. Fatigue curves, therefore, were obtained on material in various stages of coarsening using an R. R. Moore fatigue testing machine. A circumferentially grooved specimen ($\frac{1}{8}$-in. radius) was used in place of the standard specimen to provide a slight stress concentration factor (about 1.2) to make the tests more sensitive to slight material differences. The endurance limits obtained are listed in Table I, and the corresponding fatigue curves are shown in Fig. 25. Diminution of the endurance limit occurs only when the fracture is very bad (group 6). Not only are the endurance limits nearly identical for the first four or five groups in the fracture standards but the general shape of the curves as well. Thus, a few cycles of overstress would be no more harmful in a mildly coarsened engine part than if made of steel with a normal fracture.

Other fatigue data[5] were obtained on larger size test bars using a specially designed machine of the cantilever-beam type operating at 1000 rpm. The specimen used (see Fig. 26) had a critical diameter of 1-in. and contained a fillet which provided a stress concentration factor of approximately two (2.0). Material with a normal fracture was tested in comparsion with material from the same heat of steel coarsened similarly to that in Fig. 4(*c*) (see Fig. 27). After complete heat treatment to 331 to 341 Brinell the bars were finished machined and nitrided for 36 hr. at 950 F. The object in nitriding the bars was to determine whether the penetration of nitrides into the steel from the nitriding process, in conjunction with the grain coarsening present, would cause a lowering of the

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[5] Unpublished data obtained by J. M. Lessells, Mass. Inst. of Technology, Cambridge, Mass.

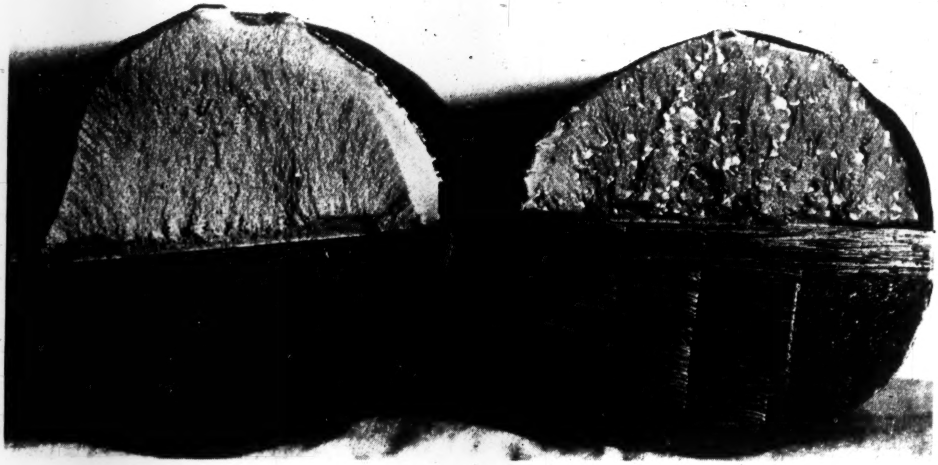


FIG. 27.—Material for Large Size Fatigue Tests.

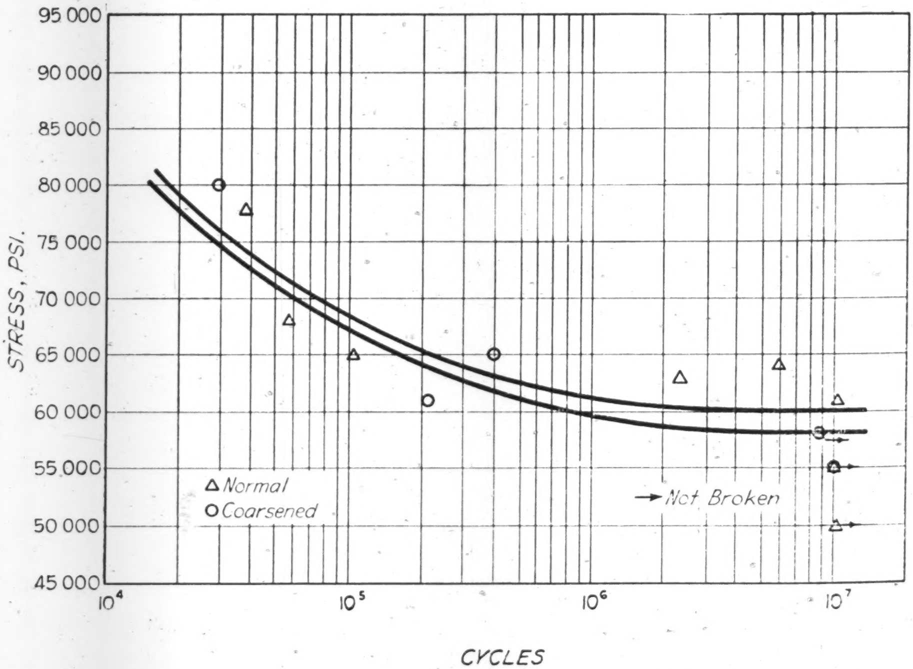


FIG. 28.—Fatigue Tests Of Coarsened Material Nitrided.
1-in. critical diameter stress concentration specimens.

endurance properties when compared to the uncoarsened material, also nitrided. The answer to this question was of great interest because of the large numbers of crankshafts made of S.A.E. 4340 and similar steels which are nitrided. The physical properties obtained on the material before nitriding are listed below:

	Series	Yield Point, psi.	Tensile Strength, psi.	Elongation, per cent	Reduction of Area, per cent	Izod Impact, ft-lb.	Brinell Hardness Number
No. 1....	Normal	154 500	163 500	18.0	49.3	46	341
No. 2....	Coarsened	150 000	159 250	18.0	49.5	45	331

The hardness of the case after nitriding varied from 548 to 657 Vickers Brinell. The fatigue results are shown in Fig. 28 and indicate endurance limits of approximately 60,000 psi. and 58,000 psi. for the normal and coarsened specimens, respectively. Actually the curves are nearly identical and could almost be superimposed but are drawn as shown for greater clarity.

CORRELATION OF TEST SPECIMENS AND FORGINGS

Concern has been expressed that the fracture test may not indicate the worst condition of grain coarsening found in the forging. This possibility is likewise true of any extrinsic, nondestructive physical test unless the steel is actually burned, in which case Magnaflux or even visual inspection may reveal the condition. In order to determine whether the fracture test is a satisfactory indicator of coarsening in the forging proper, many forgings showing various degrees of grain coarsening in the fracture test specimen were cut up and fracture tested (after complete heat treatment in the case of flame-hardened forgings). In every type of forging except one, the fracture appearance of the test specimen was as bad as or, as is true of flame-hardened fractures, worse than other sections of the forging. This is readily understandable because the fracture test specimen is generally located at an extremity of the forging where the heating condition, due to end effect, would be the most severe. The one exception previously mentioned was in the case of a master rod forging where considerable forging was performed on the test specimen end after final heating and only a small amount of work on the other end. In this case by increasing the size of the test specimen, the beneficial influence of a large amount of forging after heating was reduced and the correlation between the test specimen and the heavy section of the forging was then found to be satisfactory. Therefore, if heating conditions within the furnace are essentially uniform, and if the test coupon and the dies are properly designed to provide equivalent amounts of hot work in the test specimen and forging, the fracture test can be considered as representative of the worst condition of coarsening in the forging.

METHOD OF OBTAINING FRACTURE STANDARDS

The standards were not obtained from actual production forgings but from steel that had been purposely heated to various temperatures in order to obtain uniform standards and corresponding physical properties. No forging was performed after the heating because it was desired to obtain the effect of various types of fractures on physical properties without strict regard to how the fractures were obtained. Although it might seem that fractures obtained without subsequent forging do not simulate actual production conditions, attention is directed to the fact that some parts of many forgings receive very little working after the final heating.

The material used in the preparation

of the standards was $5\frac{1}{4}$-in. square billet stock of S.A.E. 4340 steel forged to 3-in. round by approximately 22-in. long. Groups 5 and 6 of the standards were obtained in box type furnaces operating at metal temperatures of 2500 F. and 2550 F., respectively. These temperatures are far in excess of those used in production. The group 4 fractures were obtained at a metal temperature of 2450 F. in a box furnace. This temperature is considered excessive even for plain carbon-steel forgings. Groups 2 and 3 fractures were obtained in uniformly heated well-controlled rotary furnaces, which are used almost exclusively on aircraft forgings. These fractures were obtained on two different heats of steel, of different susceptibility to overheating, with the furnace operating at 2400 F. A soaking period of 4 hr. at the furnace temperature of 2400 F. produced a steel temperature of 2350 F. The normal fractures in group 1 were obtained by heating the steel for about 2 hr. in a rotary furnace controlled at 2325 F. which is the maximum operating furnace temperature used on aircraft forgings. The metal temperature in this instance was 2250 F.

On most of the specimens, fractures were obtained for direct comparison in the flame-hardened-and-drawn condition; quenched and drawn only; normalized, quenched and drawn to 401 to 415 Brinell; and normalized, quenched, and drawn to 321 to 331 Brinell.

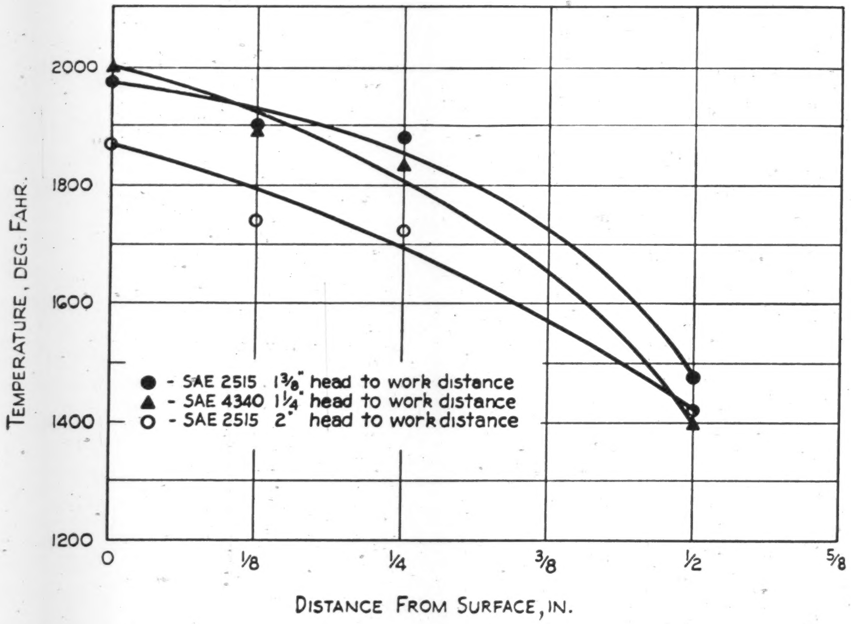


FIG. 29.—Flame Hardening Heating Curves, 3-min. Cycle.

STUDY OF THE FLAME-HARDENING PROCESS FOR USE IN FRACTURE TESTING

A thorough study has been made of the flame hardening process to determine its characteristics for use in fracture testing. Previous experience had shown that a heating cycle of approximately three minutes on large crankshafts (like that shown in Fig. 17) and propeller shafts produced satisfactory fracture results at a practical rate of testing. This long cycle (shorter time intervals are used on smaller parts) was selected for detailed analysis.

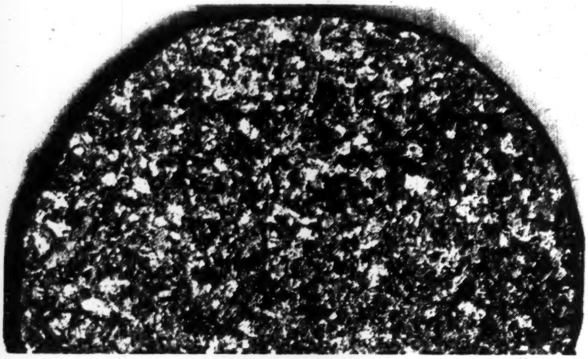
Surface temperatures reached were determined by optical pyrometer; subsurface temperatures were determined simultaneously by three thermocouples inserted respectively at $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$-in. below the heated surface on specimens which had been notched to leave approximately $\frac{5}{8}$-in. for fracturing. The surface temperature on these special test specimens, as well as on all flame-hardened test specimens, ranged between 1850 F. and 2000 F. These high surface temperature values were necessary to produce temperatures between 1400 and 1500 F. at $\frac{1}{2}$-in. below the surface within the 3-min. heating period. A temperature of 1400 F. is about the minimum which will eliminate the as-forged structure from the fracture. The temperature at a distance of $\frac{1}{4}$-in. below the surface varied between 1750 and 1850 F. Some typical heating curves are shown in Fig. 29.

The high surface temperatures as well as the steep temperature gradient were a cause for concern until direct comparison with furnace-treated fractures, as previously shown in Figs. 18(*a*), 18(*b*), 19(*a*), 19(*b*), clearly proved that the flame-hardened results are fully dependable. The respective flame and furnace-hardened fractures are essentially identical even though the flame-hardened specimens were quenched from a temperature range of 1400 to 2000 F., whereas the furnace-hardened specimens were quenched from 1550 F. The size or distribution of facets is not appreciably affected by quenching temperatures ranging from just above the lower critical to 2000 F. The failure of the high heat to refine the fracture is probably due to the short heating time used. Longer heating periods such as those usually employed in furnace heating practice would probably have more of a refining influence at the high temperature.

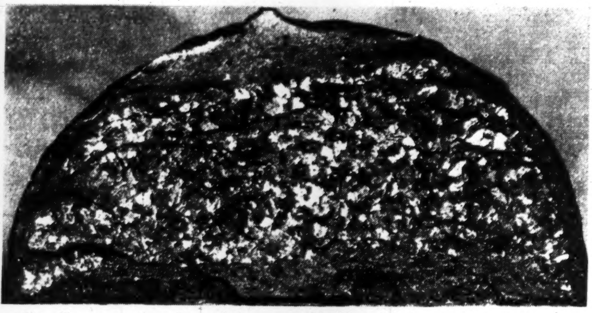
No specimens were furnace hardened from the maximum temperature reached in the flame-hardening operation because of the excellent correlation between flame- and furnace-hardened fractures. Samples, however, were quenched from a furnace at 1350 F. and 1400 F. to determine the lowest temperature which would eliminate the as-forged fracture in S.A.E. 4340 steel. Figure 30(*a*) shows a fracture of S.A.E. 4340 steel heated to 2300 F. and air cooled; Fig. 30(*b*) was oil quenched from 1350 F. and drawn at 1100 F.; Fig. 30(*c*) was oil quenched from 1400 F. and drawn at 1100 F. At 1350 F. (the Ac_1 point for S.A.E. 4340 steel) almost all of the as-heated fracture remained whereas at 1400 F. (which is 25 F. below the Ac_3 point), the structure was entirely fibrous and indistinguishable from that obtained at normal hardening temperatures. Therefore, a temperature of 1400 F. at the bottom of the flame-hardened zone is sufficient to produce a fibrous structure suitable for the detection of overheating when present.

GRAIN COARSENING AND STEEL HEAT SENSITIVITY

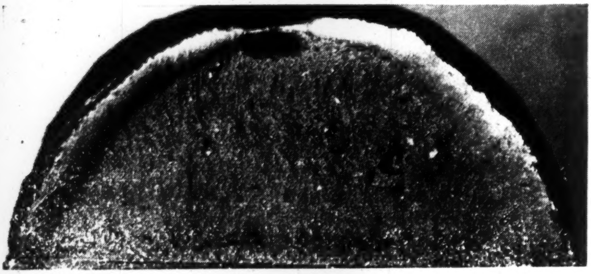
At the beginning of this paper mention was made of the fact that grain coarsening may be obtained at normal forging temperatures in uniformly heated, well-controlled furnaces. However, this coarsening at normal temperatures occurs chiefly in sections which receive little or no work after the final heating and can be minimized by avoiding excessive time at temperature; that is, by dropping the temperature of the furnace in case of short delays and removing the stock from the furnace when long delays are anticipated. Delay time of more than 1 hr. in the final heating furnace may prove detrimental to the fracture appearance of some heats of steel.



(*a*) As heated to 2300 F.



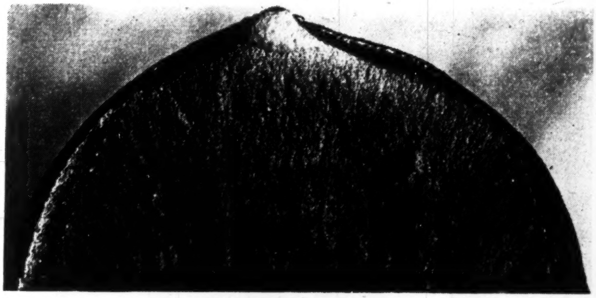
(*b*) Furnace hardened from 1350 F. and drawn at 1100 F.



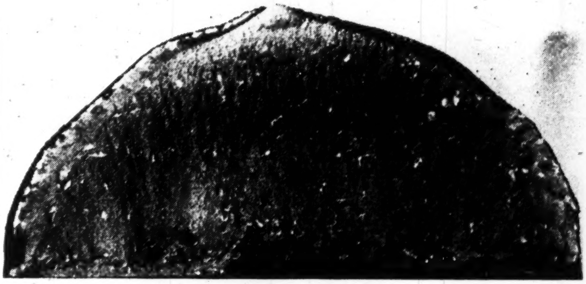
(*c*) Furnace hardened from 1400 F. and drawn at 1100 F.

FIG. 30.—Effect of Low Quenching Temperatures On Fracture.

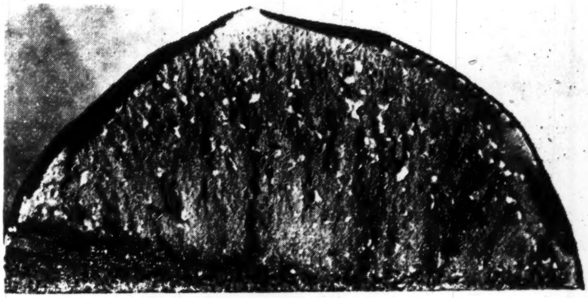
It has been clear for some time that certain heats of the same grade of steel are more susceptible to coarsening than others. An excellent illustration showing the differences among four heats of S.A.E. 4340 steel is presented in Fig. 31. Three-inch round bars from the four heats were held at temperature for 4 hr. in a rotary furnace controlled at 2400 F. During this interval the furnace doors were kept closed except for periodic checks of the stock temperature by means of an optical pyrometer. The furnace was slowly rotated during the



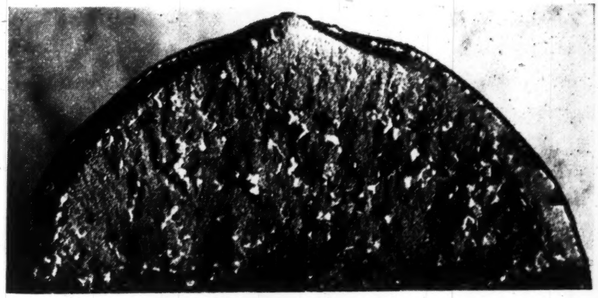
(*a*) Heat A—none.



(*b*) Heat B—trace.

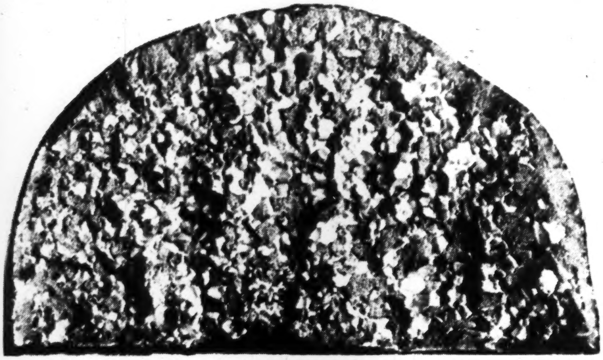


(*c*) Heat C—mild.

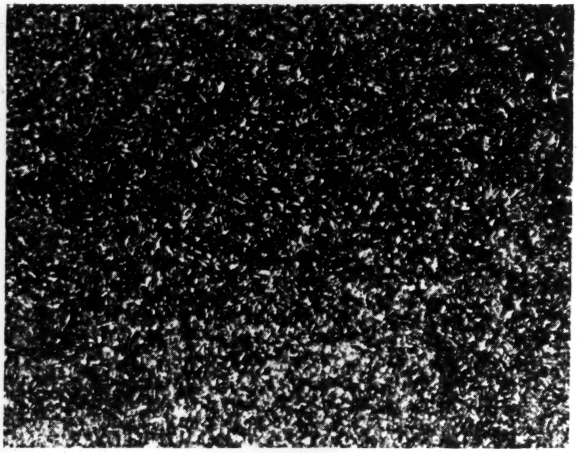


(*d*) Heat D—mild to bad.

FIG. 31.—Relative Coarsening Susceptibility—Heated 4 hr. in Rotary Furnace at 2400 F.



(*a*) Fracture.



(*b*) Microstructure (× 150). Etched in Nital.

FIG. 32.—Typical Microstructure of Coarsened Steel.

heating period to insure uniformity of heat distribution. The maximum stock temperature attained was 2350 F. Relatively similar, although not as pronounced, fractures were obtained by heating these same heats for 4 hr. in a rotary at 2350 F.

To accentuate the difference between the heats, the fractures shown in Fig. 31 were quenched and drawn only. These fractures correspond to groups 1, 2, 3, and 4 in the fracture standards.

The heats were carefully analyzed to determine whether any differences could be detected chemically. The results of these analyses are shown below:

	Heat A	Heat B	Heat C	Heat D
Fracture	None	Trace	Mild	Mild to Bad
Carbon	0.42	0.41	0.44	0.42
Manganese	0.66	0.71	0.70	0.67
Phosphorus	0.018	0.016	0.017	0.015
Sulfur	0.014	0.019	0.015	0.015
Chromium	0.80	0.82	0.82	0.80
Nickel	1.79	1.77	1.77	1.78
Silicon	0.24	0.32	0.25	0.23
Molybdenum	0.25	0.23	0.23	0.25
Aluminum[a]	0.03	0.02	0.02	0.02
Nitrogen[a]	0.013	0.014	0.010	0.011
Grain Size	8/7	6/7-5	8/7	7/6-5

[a] Determined by South Works Laboratory of Carnegie-Illinois Steel Corp.

The analyses are literally identical including aluminum and nitrogen, and hence no clue to the difference in behavior can be garnered from this study of chemical composition. Neither does the McQuaid-Ehn grain size furnish any information concerning the behavior of the steel at more elevated temperatures; heats A and C were very fine grained whereas B and D were somewhat coarser. All four heats were made at the same mill so that none of the difference can be laid to variations in steel mill practice.

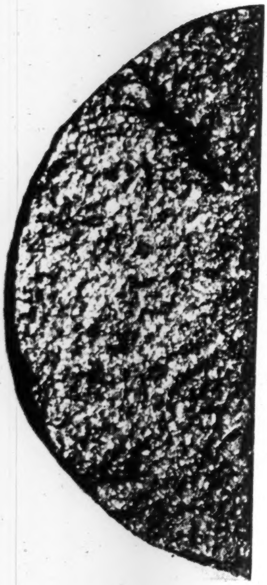
The appearance of facets in the examples shown is not peculiar to chromium-nickel-molybdenum steel alone (S.A.E. 4340) but has been observed in plain carbon steel (S.A.E. 1045), in chromium-molybdenum steel (S.A.E. 4140), in chromium-nickel steel (S.A.E. 3140 and 3312), and in nickel steel (S.A.E. 2515). The condition has not been observed in chromium-vanadium steel (S.A.E. 6140) even when sufficiently overheated to result in partial melting of the metal. The lower alloy and plain carbon steels appear to require higher temperatures to cause grain coarsening than the higher alloy steels, but this cannot be made as a general statement because of the difference in susceptibility of various S.A.E. 4340 heats. Thus the facet condition may not be more inherent in this type of steel but simply more sensitive to the mechanism of coarsening which as yet has not been satisfactorily explained.

METALLOGRAPHIC STUDY OF GRAIN COARSENING AND OVERHEATING

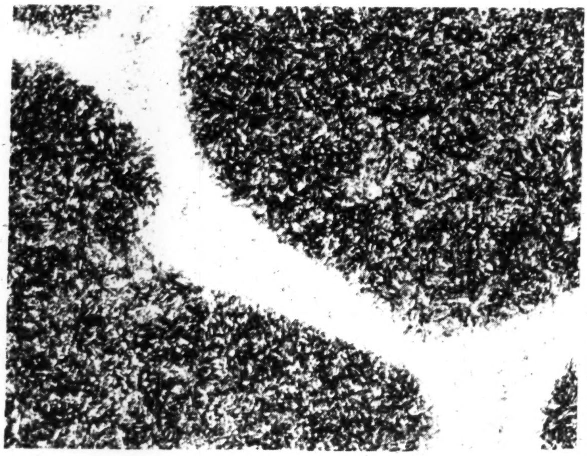
The Widmanstätten structure, which is sometimes associated with overheating in plain carbon steel, does not persist through heat treatment in the alloy steels investigated. No evidence of any constituent which might be responsible for the facet condition in these steels has been observed microscopically. Even the microstructure of the steel (S.A.E. 4340) from the badly coarsened fracture in Fig. 32(*a*), which was fully heat treated, has the same appearance as steel with a normal, fully fibrous fracture. This applies equally in the unetched, lightly etched, or normally etched conditions. The microstructure from the fracture in Fig. 32(*a*) is shown in Fig. 32(*b*) with a normal nital etch. Various methods of polishing and etching, including electrolytic and the Wesley-Austin reagent (10 per cent nitric acid, 10 per cent sulfuric acid, balance water) which British metallurgists have found helpful in the examination of overheated steel, have been tried without success in an attempt to determine the nature of the grain coarsening mechanism.

Steel which was very badly overheated, if not actually burned, may be detected microscopically. The microstructure of the steel (also S.A.E. 4340) in the fracture in Fig. 33(*a*) shows decarburized coarse grain boundary outlines for about $\frac{1}{4}$-in. below the decarburized surface layer (see Fig. 33(*b*)). Below the zone of decarburized grain boundaries, the outline of coarse grain boundaries is still readily apparent (with a light nital etch) in the form of small elongated inclusions (see Fig. 33(*c*)). At higher magnification (Fig. 33(*d*)), these inclusions were identified as sulfides. The principal value of the light etch is to provide better contrast to make the coarsened grain boundaries stand out more sharply. With a normal etch, the coarse grain boundaries are nearly obscured except in the decarburized grain boundary zone.

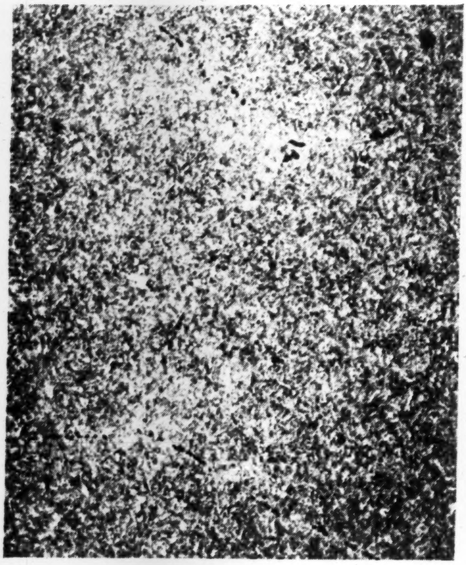
Whether grain coarsening is caused by the same mechanism as in the above instance, that is, the rejection of sulfides to the grain boundaries, is not known. No evidence of sulfides outlining grain boundaries has been noted in microstructures from normal or grain coarsened fractures, but this may be only because the particles are extremely fine and well dispersed or are actually sub-microscopic. Difference in appearance of deep acid



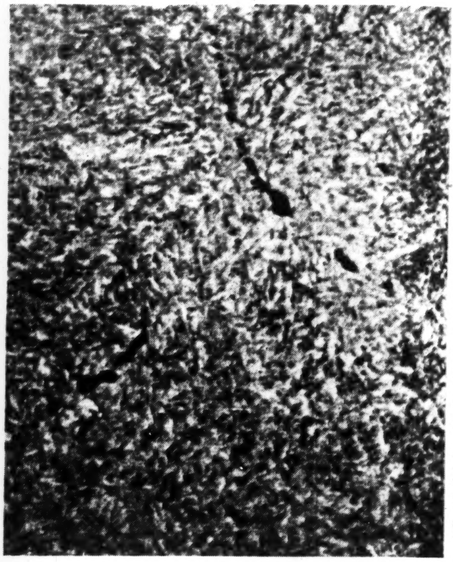
(a) Fracture.



(b) Microstructure near surface (× 150).



(c) Sulfide grain boundaries 1 in. below surface (× 150).



(d) Sulfide grain boundaries 1 in. below surface (× 500).

etched cross-sections from the same pieces as the fractures in Figs. 32(*a*) and 33(*a*) cast doubt upon the similarity of the mechanism in the two cases. An etched section from the fracture in Fig. 32(*a*) has the characteristic appearance of steel with a normal fracture (see Fig. 34(*a*)), whereas, an etched section from the fracture in Fig. 33(*a*) shows a pronounced and nearly continuous outline of coarse grain boundaries (see Fig. 34(*b*)). The grain boundaries brought out by etching in Fig. 34(*b*) are not revealed by Magnaflux inspection prior to etching.

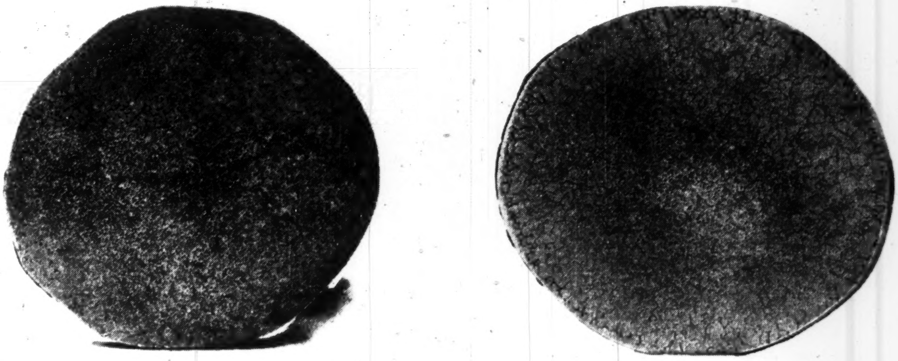

(*a*) From material of fracture in Fig. 32(a). (*b*) From material of fracture in Fig. 33(a).

FIG. 34.—Etch Slices.

The appearance of the fracture produced by hot fracturing suggested a possible explanation of the nature of grain coarsening. Previous studies of grain coarsening were made on material in the quenched and drawn condition which largely destroyed, for metallographic purposes, the effect of the previous high temperature heating operation. It was considered necessary, at that time, for the steel to be heat treated before the coarsened grains could be distinguished from the general mass of the steel. However, when green stock which showed grain coarsening upon hot fracturing was examined metallographically, the nature of grain coarsening became more evident.

The fracture of the material used in this study is shown in Fig. 32(*a*) in the quenched and drawn state. A piece from the same specimen in the green condition was broken cold producing a fracture similar to that in Fig. 9(*a*); the same piece was again broken a short distance away at 450 F. resulting in a fracture similar to that in Fig. 32(*a*). A single microsection was then cut through the piece containing both fractures. The polished and etched section is shown in Fig. 35 at approximately 6 magnifications. The left edge of the microsection is taken through the cold fracture and shows that the flat areas in Fig. 9(*a*) have no relationship to individual grains but are simply transcrystalline breaks through similarly oriented grains. The hot fracture (on the right edge) appears to be chiefly intercrystalline. Examination of the fracture shows that these intercrystalline breaks coincide with facets.

Where no facets are present, the fracture is fibrous and again transcrystalline. Likewise in other samples of similar grain size where no facets were present at all, the break was as straight as on the left side of Fig. 35 except that the fracture was fibrous instead of crystalline.

Microscopic examination at high magnification of the grain boundaries which show facets reveal no constituent at the grain boundaries which might be responsible for the facets. Facets, therefore, appear to be the remains of persistent large grains formed at the forge heating temperature which are not fully refined by ordinary heat treatment. No explanation, however, is yet available for the persistence of large grains in certain heats and not in others under identical initial heating conditions.

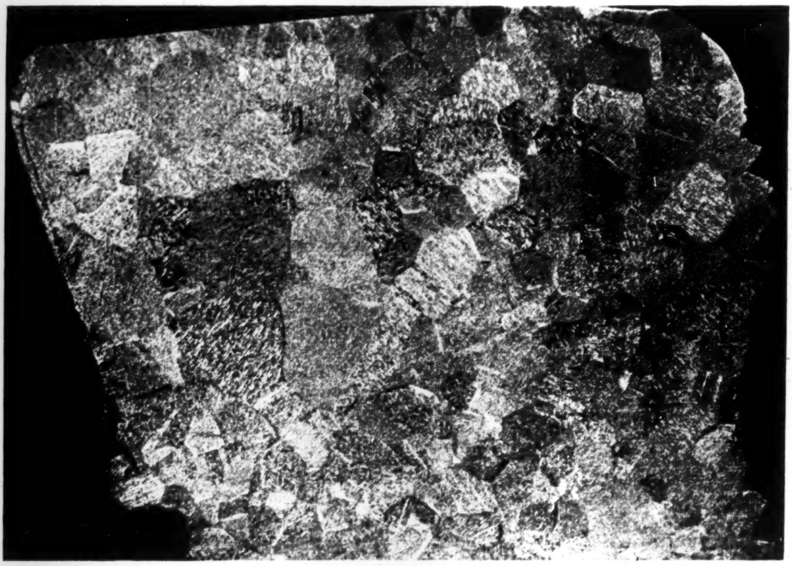
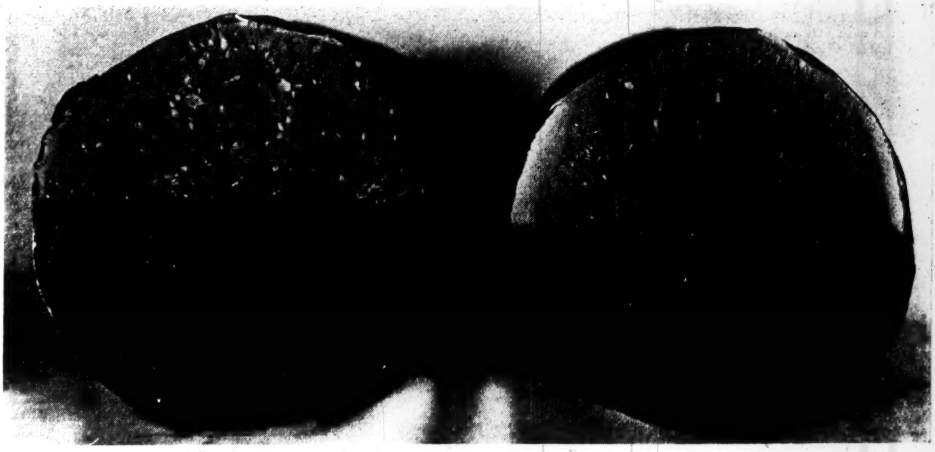


FIG. 35.—Green Stock—Cold Fracture Left Side, Hot Fracture Right Side (× 6). Etched with Vilella's Reagent.

Small specimens of ½-in. square S.A.E. 4340 steel were heated to 2300 F., 2400 F., and 2500 F. in a carbon combustion furnace and cooled at three different rates to determine the effect, if any, of the cooling rate from the forging temperature on the resulting fracture and microstructure. One set was oil quenched directly, another set air cooled, and the third set buried in warmed sand to promote slow cooling. The specimens were broken immediately after cooling from the high temperatures and again after complete heat treatment. The fractures after direct oil quenching without subsequent heat treatment had a shiny euhedral appearance not unlike the fracture in Fig. 6(*a*). The more slowly cooled fractures were flat, coarsely crystalline, and similar in appearance to Figs. 8(*a*) and 9(*a*). In spite of the difference in fracture appearance immediately after cooling, the fractures after complete heat treatment were very similar. Likewise the microstructures obtained on the specimens after complete heat treatment were indistinguishable. Hence it may be concluded that the cooling rate from the forging temperature has no effect on the final fracture appearance.

REFINEMENT OF GRAIN COARSENED STEEL

Steel coarsened similarly to that in the first five groups of the fracture standards can readily be refined both by heat treatment and forging while group 6 fractures appear to be incapable of salvaging short of remelting. This further suggests that one mechanism may be responsible for the fracture appearance in the first five groups while an entirely different mechanism, perhaps incipient fusing of the grain boundaries, may cause the brittleness of the material in group 6.


(*a*) Coarsened structure. (*b*) Same after re-heating 1 hr. at 2300 F.

Both specimens are shown in the fully heat treated condition.

FIG. 36.—Salvage of Grain Coarsened Steel By Heat Treatment.

Mildly coarsened, fully heat-treated steel similar to that at the left in Fig. 36 can be completely refined by a reduction in area in forging of 20 per cent or more. Essentially complete refinement can be obtained by simply reheating to the normal forging temperature for an hour or two. The fracture at the right of Fig. 36 was obtained on the same piece of steel as the fracture on the left by simply reheating in a furnace at 2300 F. for 1 hr. without subsequent forging. Reheat treatment or repeated normalizing at the regular temperature appears to have only a minor effect on refining the fracture. Reheating to low forging temperatures evidently produces greater atomic mobility which effectively breaks up the persistent large grains and the fracture appearance is improved. Steel severely overheated or burned cannot be reclaimed even by forging. Salvage of borderline coarsened material is a dubious process as reheating to the forging temperature without subsequent forging produces heavy scaling which might necessitate the scrapping of forgings with little finish. If forging heats and delay times are carefully controlled, few forgings should have to be scrapped for poor fractures. For these few, the expense and uncertainty of salvage is scarcely justified.

QUALITY IMPROVEMENT

The fracture test when properly applied will result in a marked improvement in the quality of alloy-steel forgings because the actual condition of the metal in the forgings can be better appreciated by visual examination of the fracture than by perusal of physical property data. By establishing heating conditions (time and temperature) in accordance with fracture appearance, forgings with poor physical properties because of grain coarsening will be negligible in number. By applying to all alloy forgings the heating conditions found necessary to control coarsening in the fracture tested forgings, scrap as a result of heavily scaled stock will be reduced and the extent of surface decarburization decreased.

Acknowledgments:

The authors gratefully acknowledge the generosity of the officers of the Wyman-Gordon Co. in granting permission to publish the full details of this work. Also deeply appreciated is the splendid cooperation of the Metallurgical Laboratory, particularly of Henry Anker, Jr., for the fracture photographs, of James Daanen for the charts and photomicrographs, and of James Dehn for very able assistance in preparing the fractures. Credit is also due to the Worcester (Mass.) Laboratory of the Wyman-Gordon Co. for some of the ideas and suggestions, such as the use of flame hardening, which are embodied in the report.

DISCUSSION

MR. A. A. BRADD[1] (*by letter*).—We have used fracture testing as part of our inspection on forgings for over two years, and would like to add the following comments:

The one fault which we have found with the use of fracture testing as a control over the acceptance of heat-treated forgings has been with forgings fabricated from heats of low hardenability. Since the fracture coupon is usually of smaller cross-section than the actual forging, we have found that some heats show completely acceptable fractures and surface hardnesses, yet tension tests on bars machined from the forgings failed to comply with specification requirements. The obtaining of satisfactory tensile results from test bars machined from a heat-treated bar of the same cross-sectional area as the forging intended to be fabricated from the heat of steel did not give adequate assurance that all forgings made from that heat, showing acceptable surface Brinell hardnesses and satisfactory fractures, would meet the tensile requirements of the specification. This may be due to variation in quenching practice between that given the test bar and that given to the actual forgings, or variation in hardenability throughout a heat.

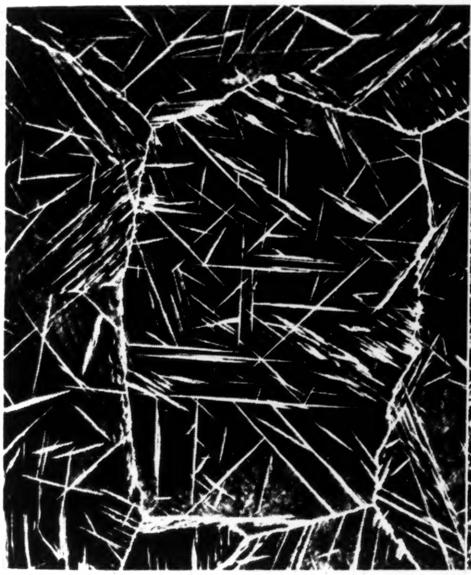


FIG. 1.—S.A.E. 4340 Steel which Was Severely Overheated During Carburizing.

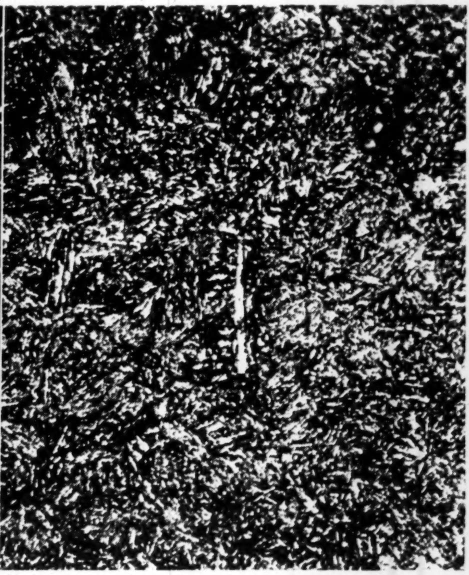


FIG. 2.—Same Steel as Fig. 1. After Normalizing at 1650 F., Hardening at 155 F., and Drawing at 900 F.

Examination of approximately 200,000

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[1] Laboratory Director, Remington Rand, Inc., Propeller Div., Johnson City, N. Y.

fractures from hundreds of different heats of steel have not revealed any to be of the "facet" type.

Our tests confirm the finding of the authors that the Widmanstätten structure produced by overheating S.A.E. 4340 steel does not persist through heat treatment. The accompanying Fig. 1 shows a sample of S.A.E. 4340 steel which was severely overheated during carburizing for the determination of the McQuaid-Ehn grain size, due to the failure of the temperature regulator. The accompanying Fig. 2 shows the same piece of steel after normalizing at 1650 F., hardening at 1550 F., and drawing at 900 F.

MR. C. H. LORIG[2] (*by letter*).—The paper gives an excellent description of the fracture appearance of steels characterized by the presence of large facets in a normal, fibrous heat-treated structure. Repeated reference is made to "grain coarsening" when speaking of the presence of the large facets, and while the authors explain that the facets are "ghosts" of the coarse grains which exist at the forging temperature, the casual reader is prone to reason that the facets are evidence of coarse grains that persist after heat treatment. Such is not the case. There is no evidence that the coarse grains do persist. What is more obvious, the "ghosts," referred to by the authors, apparently show the existence of surfaces of weakness which were austenitic grain boundaries at forging heat (probably surfaces where constituents deleterious to the strength of the metal have precipitated during the heating cycle for forging). On subsequent heat treatment, the structure of steels showing the coarse facets is refined as thoroughly as is the structure of steels that do not show the facets. The difference is that, on fracturing, the fracture of steels susceptible to coarse facet formation may follow certain paths offered by weakened surfaces that formerly outlined the austenite grain existing at forging heat. The presence of the facets is, therefore, no indication that the steels are coarse grained after heat treatment.

The authors do not attempt to explain the cause or causes for the large facets. It would seem necessary in undertaking a study of the causes for the fracture to consider the melting practice, and particularly the deoxidation procedure and its influence on the distribution of sulfides and other nonmetallics in the steel.

MR. A. L. RUSTAY[3] (*by letter*).—The fracture test has been of considerable practical importance in controlling and improving forging practice, but the application of the test to a particular forging should be approached intelligently. The test coupon must be of the correct size and shape and must be located so that it reflects the least desirable forging condition that may exist at any time. It must be given the proper amount of hot work in each die impression so that it duplicates the hot work done on the forging. At the same time, these considerations must not be interpreted so that it becomes more difficult to produce the test piece than the forging. On page 435 of the paper, in their discussion of the metallographic study of grain coarsening, the authors mentioned the Wesley-Austin[4] reagent. We have used the Wesley-Austin etchand, an electrolytic hydrochloric acid etch, alkaline sodium picrate electrolytically in an attempt to identify the grain boundary material without much success. The accompanying Fig. 3 shows a typical metallographic structure obtained with the Wesley-Austin etch on a fracture corresponding to Fig. 4(*a*) of the paper. There is some indication that the Wesley-Austin etch will show the beginnings of coarse grains when a normalized, quenched-and-drawn steel shows no visible facets but has a smooth, uniform, matte fracture. The reference quoted is an interesting study of the problem of overheating and burning and offers an explanation of the mechanism. We do not feel that the authors' explanation necessarily applies to overheating and grain coarsening although it may be the proper explanation of the formation of excessively coarse grains due to actual burning.

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[2] Supervising Metallurgist, Battelle Memorial Inst., Columbus, Ohio.

[3] Wyman-Gordon Co., Worcester, Mass.

[4] "First Report of the Alloy Steels Research Committee," Sec. X, p. 189, published by the British Iron and Steel Institute.

It would be interesting and of value to forging establishments if the occurrence of the grain coarsening could be placed in a particular place in the forging or heating operations. At present, it appears as though it may occur at different times during the forging sequence for different jobs and it is somewhat difficult to predict when a job is apt to show this grain coarsening. It should be noted that contrary to the authors' opinion, we have observed that S.A.E. 3312 type steel seems to behave somewhat differently than 4340 or medium carbon alloy grades. The facets or euhedrons are frequently much finer in appearance, and sometimes a fracture that has a smooth matte appearance to the eye will show numerous, but quite small euhedrons when examined under a binocular microscope at about ten magnifications.

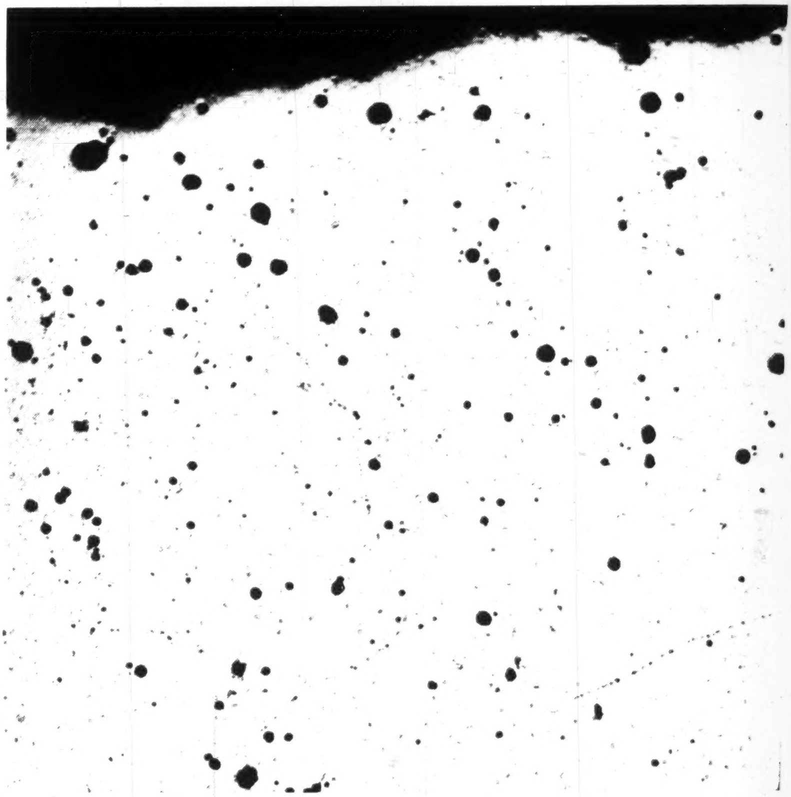

FIG. 3.—Typical Metallographic Structure Obtained with the Wesley-Austin Etch.

On page 438, the authors describe work

that they have done to demonstrate that the cooling rate from the forging temperature has no effect on the final fracture appearance. Based on a limited amount of work, it seems as though this experimental work should be repeated because discrepancies have been observed in attempting to duplicate the author's results.

If the authors' work can be confirmed and it can be proven that 20 per cent reduction of area is sufficient to refine mild coarsening, then we will have a very good rule of thumb to use in setting up jobs for production forging. In other words, the parts should receive about 20 per cent reduction after the last reheat.

MR. H. B. FERNALD[5] (*by letter*).—The findings presented in this paper agree substantially with the results obtained at the Cincinnati plant of the Wright Aeronautical Corporation. In fact, the authors have gone considerably further than we have in some phases of their investigation.

Although their statement that "the fracture standards and most of the discussion on fractures are generally applicable to other alloy steels such as S.A.E. 2515 (AMS 6242) and S.A.E. 3312 (AMS 6250)" is probably true, it is suggested that the carburizing type of steels present some differences from the through hardening types and that a certain amount of direct substantiation should be obtained before applying these data indiscriminately. Furthermore, it is not ordinarily feasible to set up an absolute acceptance and rejection standard for all cases; it is sometimes possible that a slightly greater degree of grain coarsening can be tolerated in some applications than in others, although none of it is desirable.

In the use of a tong hold or other integrally forged fracture specimen, great care must be exercised to assure that such a specimen truly represents the worst conditions to be found in the forging proper, as pointed out in this paper. In this connection, we should like to see a paper summarizing the experience in relating surface conditions with internal structure; admittedly such a study does not lend itself to scientific treatment at the present time, but some correlation is possible.

All in all, the authors have done a commendable piece of work and should be warmly congratulated.

MR. JOHN M. LESSELLS[6] (*by letter*).—The paper by Messrs. Haworth and Christian is a very valuable contribution to the literature of the forging and heat treatment of alloy steels.

The question which interests the engineer is to what extent such grain coarsening reduces the fatigue strength. Although some fatigue results obtained by the writer are contained in the paper it may be of interest to add some additional values obtained on S.A.E. 4340 steel.

For the unnitrided state and a normal condition the endurance limit value for the bar with stress concentration shown in Fig. 26 of the paper was found to be ±28,000 psi., the corresponding tensile strength being 156,000 psi. With similar steel, coarsened at 2550 F., giving a fracture similar to that shown in Fig. 32(*a*) the endurance limit was found to be unchanged at a value of ± 28,000 psi.

It therefore appears that the fatigue strength under stress concentration is not affected by the degree of coarsening.

MR. E. L. BARTHOLOMEW, JR.[7] (*by letter*).—The authors are to be complimented on making this contribution to fracture testing of alloy steels. It is hoped that this work will be continued so that a better understanding of the underlying causes of grain coarsening in such steels will be forthcoming.

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[5] Laboratory Manager, Cincinnati Plant, Wright Aeronautical Corp., Cincinnati, Ohio.

[6] Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[7] Assistant Professor of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Some studies have been made by the writer at the Massachusetts Institute of Technology in collaboration with Prof. J. M. Lessells and on the basis of this work the following contributions are made to this discussion.

Steels heated for hot working attain their largest austenite crystal size at the top forging temperature. For the same temperature this size may well vary from heat to heat of the same type of steel. However, it seems that the fracture of the subsequently heat-treated specimens may not only indicate coarsening tendencies in some cases but the extent to which the heat treatment was successful in effecting a refinement. Is it possible that one heat of steel which develops a prohibitively coarse austenite at forging temperature might be completely refined by heat treatment while another heat of the same steel developing a lesser austenite crystal size at the same forging temperature under similar conditions might be incompletely refined by heat treatment? In other words, is it true that steels may show different susceptibility to coarsening as well as varying response to refinement by subsequent heat treatment? Figure 31 of the paper might serve as an illustration of this point. The steels shown were heated and probably cooled similarly. They were then quenched, drawn, and fractured. From the photographs it appears that the size of the large facets is approximately equal in the three steels. The striking difference is the variation in the number of these facets remaining after heat treatment. It might be interesting to determine the actual austenite grain size attained in these four steels after simply holding at 2400 F. and cooling. The authors state that quenching and drawing was used, "to accentuate the difference between the heats." To what extent does this heat treatment indicate the readiness of the coarse austenite to be refined?

The preceding thoughts should not be considered as questioning the adequacy of the test for its intended purpose. The authors have verified its utility under production conditions. Rather, it is the object of this discussion to inquire into the behavior of the steels and the significance of the fracture. With this objective in mind, the writer carried out an investigation on some of these same steels in an attempt to reveal microscopically the actual high temperature austenite grain size. Both Wesley-Austin and Vilella etching reagents were used in this study. A technique was developed whereby the Wesley-Austin etch could be used successfully on certain of the steels possessing suitable conditions of prior treatment. In an unpublished report on the subject representing work done in collaboration with Prof. J. M. Lessells, the following conclusions were made.

1. The prior austenite grain size is successfully revealed in S.A.E. 3312 steel with the Wesley-Austin etch only where the steel has been heated above its apparent "coarsening temperature."

2. All steels (S.A.E. 3312, 4340, and 2515) which had simply been heated to a given forging temperature, soaked for a definite interval and then allowed to air cool without any forging were less satisfactorily etched to show austenite structure with the Wesley-Austin etch than in cases where either forging or heat treatment, or both, followed the initial high-temperature heating.

3. All of the steels which were heated to the forging temperature, air cooled or forged and in either case finally heat treated, showed with Vilella's etch only the actual austenite grain size developed by heat treatment even where coarse crystals were evidenced by the fracture test.

4. The Wesley-Austin etch in all cases cited above brought out the persistence of austenite structure resulting from heating for forging, or forging, and not the grain size resulting from subsequent heat treatment.

5. The S.A.E. 2515 steel was the most difficult of the steels to etch and the Wesley-Austin etch is not considered adequate, at least on the sample of this steel available for experimentation.

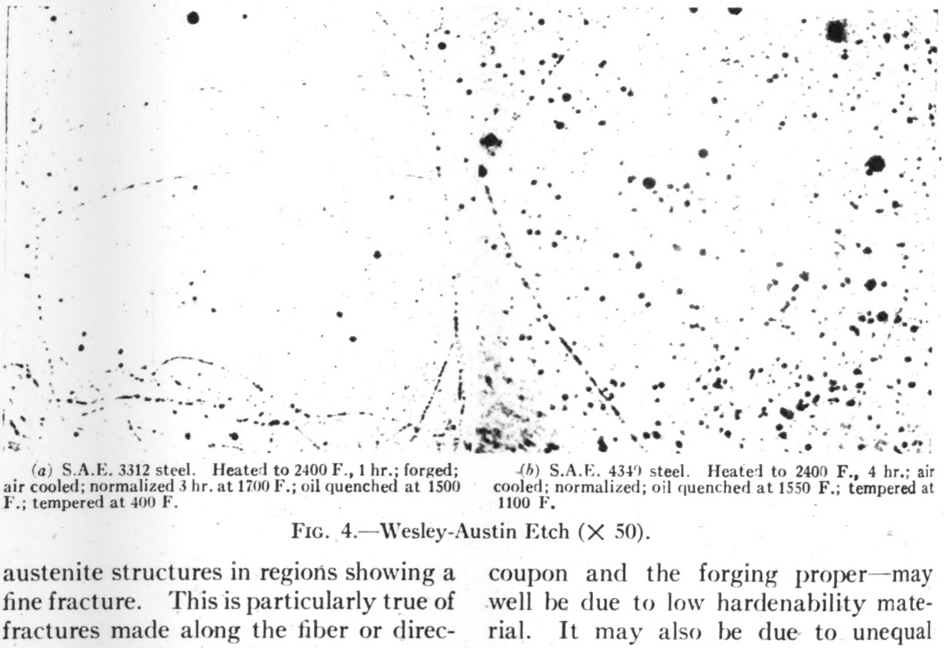
6. The Wesley-Austin etch will in certain instances bring out coarse prior austenite structures in regions showing a fine fracture. This is particularly true of fractures made along the fiber or direction of metal flow resulting from forging.

7. The persistence of high-temperature austenite structure revealed by the Wesley-Austin etch and as large facets in the fracture tests of S.A.E. 3312 and 4340 steels might be attributed to the presence of a form of carbide which locates and persists in the boundary regions of the high-temperature austenite structure.

The accompanying Fig: 4 illustrates the effectiveness of the Wesley-Austin etch in revealing prior austenite boundaries even after heat treating.

It is the writer's intention to continue this work in an attempt further to clarify coarsening behavior, forging effects and the role of heat treatment in the refinement of coarsened steels of this type.

MESSRS. A. F. CHRISTIAN AND R. HAWORTH (*authors' closure by letter*).—The authors appreciate very much the comments on their paper. The trouble experienced by Mr. A. A. Bradd—improper correlation between the fracture coupon and the forging proper—may well be due to low hardenability material. It may also be due to unequal amounts of reduction during the final forging operation. The reduction of the smaller diameter test coupon may have been sufficient to break up the coarse grains, whereas the forging proper was not worked sufficiently to accomplish the same results. The fracture coupon should be so designed that the amount of reduction during the final forging operation will be equivalent to that of the forging proper.



(*a*) S.A.E. 3312 steel. Heated to 2400 F., 1 hr.; forged; air cooled; normalized 3 hr. at 1700 F.; oil quenched at 1500 F.; tempered at 400 F.

(*b*) S.A.E. 4340 steel. Heated to 2400 F., 4 hr.; air cooled; normalized; oil quenched at 1550 F.; tempered at 1100 F.

FIG. 4.—Wesley-Austin Etch (× 50).

With regard to satisfactory acceptance tests being no guarantee that the forgings themselves would pass customers' requirements, preliminary tests should be made on samples from the high and low points of the heat thereby taking care of any variation in hardenability. It is important that the forgings be given at least as thorough a quench as the test coupons. An occasional check on a forging should give assurance that they will be satisfactory.

Mr. Lorig has clearly described the mechanism of facet formation. In addition to the evidence of coarse grains at the forging temperature as shown by the fracture, both Messrs. Rustay and Bartholomew have brought out such grain boundaries with the Wesley-Austin etch. Melting practice undoubtedly has considerable influence on grain coarsening temperatures and facet formation.

Mr. Rustay has emphasized the importance of test coupon size and location and the intelligent interpretation of fracture appearance. Mr. Fernald also emphasizes this point. We agree that the facets of S.A.E. 3312 steel are generally finer than that of the medium carbon-alloy grades.

In reply to Mr. Rustay's contention that cooling rate from the forging temperature may affect the facet appearance after subsequent heat treatment, we wish to state that we performed the same experiment on S.A.E. 3312 steel and obtained entirely different results than we did on S.A.E. 4340. In the case of S.A.E. 3312, oil quenching from 2540 F. showed almost complete suppression of the facets whereas on air cooling numerous large facets appeared. We do not know if this difference is characteristic of the two types of steels or simply peculiar results obtained in our two experiments. In either case, the information is of little practical importance since quenching from the forging temperature is impractical.

Although we have not attempted a correlation between surface appearance and internal structure, it is our observation that coarsening must be quite severe before it can be noted on the surface in the form of "chicken wire" structure.

We appreciate Mr. Lessells' confirmation that a considerable amount of grain coarsening does not affect fatigue strength under stress concentration. Since the majority of aircraft engine failures are in fatigue, this statement should alleviate the worries of aircraft metallurgists on this point.

Mr. Bartholomew's point in questioning whether the coarse grains produced at the forging temperature of one heat might not be refined to a greater extent than those of another heat during subsequent similar heat treating operations has been investigated. The four heats shown in Fig. 31 were carburized at 2300 F. and slowly cooled. There was no appreciable difference in the size of the grains produced by this treatment which were of the order of (−1) and (−2). However, considerable difference in fracture appearance was produced by the subsequent heat treatment as shown in Fig. 31.

Mr. Bartholomew evidently missed the word *only* in the statement "To accentuate the difference between the heats, the fractures shown in Fig. 31 were quenched and drawn only." The samples were given the least heat treatment possible to bring out grain coarsening. A prior normalizing treatment would have caused some grain refinement and less contrast in fracture appearance. The authors are in agreement with the conclusions in the discussion, and are pleased to note that the Wesley-Austin etch has been successfully used by others to bring out the boundaries of grains found during the heating and forging operations.

THE EFFECT OF COMBINED STRESSES ON THE MECHANICAL PROPERTIES OF STEELS BETWEEN ROOM TEMPERATURE AND −188 C.

By D. J. McAdam, Jr.,[1] G. W. Geil,[1] and R. W. Mebs[1]

Synopsis

Tension tests were made of unnotched and variously notched specimens of carbon steels and alloy steels at several selected temperatures between room temperature and that of liquid air (−188 C.). Comparison is made with results obtained with some non-ferrous metals. Results are presented in diagrams of various types, which reveal the influence of combined stresses and stress concentration on mechanical properties at various temperatures. Other diagrams show the quantitative variation of these properties with temperature.

The accelerated increase of the yield stress and decrease of ductility of iron and steels with decrease of temperature is anomalous. A "normal" metal shows not more than 75 per cent increase of yield stress and no decrease of ductility with decrease from room temperature to −188 C.

The mechanical properties to be considered are: resistance to plastic deformation, resistance to fracture, and ductility. The resistance of a metal to plastic deformation cannot be completely represented by a single stress value. It is a function of the three principal stresses,[2] and varies with the temperature, amount of plastic deformation, and rate of deformation. As shown in previous papers by the authors (**4–9**),[3] the technical cohesive strength of a metal, its resistance to fracture, is also a function of the three principal stresses. These papers also show that plastic deformation and temperature affect the technical cohesive strength about as much as they affect the flow stress.[4] Moreover, there is scattered evidence that the rate of deformation also affects the technical cohesive strength about as much as it affects the flow stress.

For a specific temperature, amount of prior plastic deformation, and rate of deformation, the *technical cohesive strength,* of a brittle metal may be represented by a curved surface in a diagram with the three principal stresses as coordinates, and the *initial* technical cohesive strength of a ductile metal may be pictured approximately by a similar curved surface outside the surface representing yield, but inside the surface representing fracture after the varying plastic deformation. Any point on a technical cohesion surface represents a *technical cohesion limit.*

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[2] Any stress system may be resolved into three principal stresses normal to three mutually perpendicular planes known as the "principal planes," on which there is no shearing stress. Tensile stresses are viewed as positive and compressive stresses as negative. In this paper, as in the previous papers (**4–9**), the algebraically greatest principal stress will be designated S_1, the least principal stress will be designated S_3, and the intermediate principal stress will be designated S_2.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 463.

[4] "Flow stress" is here used in its generally accepted significance to designate the greatest principal stress at yield.

In this paper, attention will be confined to stress combinations with S_2 equal to S_3, that is, combinations that are produced by tension tests of notched cylindrical specimens. The paper presents results of tension tests of specimens with various notches, at several temperatures between room temperature and −188 C. The results are shown in diagrams revealing the influence of notches and temperature on yield stress, ultimate stress, true breaking stress, and ductility. As a notch in a specimen under longitudinal tension tends to cause both transverse radial tension and stress concentration, the results reveal the influence of both these variables on the mechanical properties of steels.

A study is thus made of the simultaneous influence of the stress combination, stress concentration, and low temperature in causing brittleness. Brief consideration is also given to the influence of the rate of strain.

METHOD OF INVESTIGATION, SPECIMENS, AND MATERIALS

Stress combinations with S_2 equal to S_3 would be produced if a cylinder could be subjected to combinations of uniform axial and radial tensile stresses. The uniform radial stress may be resolved into two equal principal stresses, with the mutually perpendicular directions rotatable around the axis of the cylinder. With an unnotched specimen, such a stress system cannot be readily obtained experimentally. When a notched cylindrical specimen is subjected to longitudinal tension, however, the minimum section is under transverse radial tension (**6**). The mean radial stress tends to increase with the depth and sharpness of the notch, but is always less than the longitudinal stress. The greatest principal stress (S_1), therefore, is longitudinal. By the use of notched specimens, it is possible to investigate the influence of the radial stress ratio (S_3/S_1) on the yield stress, ultimate stress, breaking stress, and ductility. A notch also tends to induce stress concentration. The concentration of longitudinal stress is initially greatest at the periphery of the minimum section. Even slight plastic deformation, however, greatly diminishes the initial stress concentration. By the use of properly designed notched specimens, therefore, the influence of stress concentration is minimized and the influence of the radial stress ratio is revealed, as shown in this paper and in previous papers (**6–9**).

In the investigation to be described, deep notches were used so as to minimize stress concentration and reveal the effect of the radial stress ratio. The notches were all of about the same depth (k = about 0.16),[5] but the notch angle varied between 170 deg. and 45 deg. and the root radius varied from 0.01 in. to 0.08 in. Most of the notched specimens were about 6 in. long; those having large notch angles were necessarily somewhat longer. The ends of the specimens were threaded to $\frac{3}{4}$ in. in diameter. Between the threaded ends, the specimen was machined to a selected uniform diameter, and a circumferential V notch of selected angle and root radius was machined at the midsection. The notch was carefully machined so that the conical sides of the notch were tangent to the arc at the root. Care was also taken to avoid heating, bending, or appreciable cold work during the machining.

The principal metals used were carbon steels. An 0.11 per cent carbon steel and a 0.42 per cent carbon steel were tested in the annealed condition. Long cylin-

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[5] Notch depth is expressed in terms of the relative area ($k = b^2/B^2$) of the minimum cross-section, where b and B represent the minimum and maximum radii of the section, respectively. Thus the greater the notch depth, the smaller is the value of k.

TABLE I.—DESCRIPTION OF METALS.

Metal	Designation	Mechanical Treatment		Chemical Composition, per cent													
		Method	Original Rod Diameter, in.	Carbon	Manganese	Iron	Nickel	Copper	Chromium	Molybdenum	Titanium	Tin	Lead	Zinc	Phosphorus	Sulfur	Silicon
High-Purity Iron[a]	DB	as forged	0.750	<0.001	nil	...	nil	<0.002	nil	nil	nil	nil	nil	nil	<0.0005	0.0019	0.001
0.029% carbon steel	AF	as forged	0.875	0.029	0.42	...	...	...	...	...	0.225	...	...	...	...	...	0.17
0.11% carbon steel	CA	cold-rolled	1.000	0.11	0.84	...	...	...	...	...	...	...	...	...	...	...	0.05
0.12% carbon steel	CBM	cold-worked	1.000	0.12	0.82	...	...	...	...	...	...	...	...	...	0.11	0.22	0.06
0.12% carbon steel	AG	hot-rolled	1.125	0.12	0.44	...	...	...	...	...	...	...	...	...	0.020	0.021	0.25
0.20% carbon steel	T	hot-rolled	1.125	0.20	0.42	...	...	...	...	...	...	...	...	...	0.039	0.049	0.21
0.23% carbon steel	AH	hot-rolled	1.125	0.23	0.51	...	...	...	0.01	...	...	...	...	...	0.008	0.031	0.01
0.42% carbon steel	CE	hot-rolled	1.125	0.42	0.60	...	...	...	...	...	...	...	...	...	0.033	0.050	0.20
0.57% carbon steel	CF	cold-worked	1.125	0.57	0.20	...	...	...	...	...	...	...	...	...	0.008	0.015	0.24
3.3% nickel steel	Z	hot-rolled	0.625	0.34	0.72	...	3.30	...	...	...	...	...	...	...	0.018	0.017	0.26
13% Cr., 2% Ni steel	E	hot-rolled	0.875	0.09	0.48	...	2.06	...	13.3	...	...	...	...	...	...	...	0.26
17% Cr., 2% Ni steel	AZ	hot-rolled	0.625	0.11	0.70	...	1.63	...	17.40	...	...	...	...	...	0.015	0.017	0.53
Cr-Ni-Mo steel	AS	hot-rolled	0.625	0.47	0.80	...	1.80	...	1.04	0.22	...	...	...	...	0.014	0.025	0.29
Oxygen free copper	N	cold-rolled	0.875	...	...	...	...	99.97	...	...	...	...	...	...	...	...	...
Copper-tin alloy	BA	cold-drawn	0.750	...	...	<0.01	...	diff.	...	...	...	3.9	...	...	0.3	...	...
Brass	B	cold-drawn	0.875	...	...	0.08	<0.01	61.6	...	...	...	...	3.2	35.11	...	...	...
Monel metal	G	cold-drawn	0.875	0.18	0.94	1.24	diff.	28.46	...	...	...	...	...	...	...	0.007	0.10
Nickel[b]	CW	hot-rolled	1 × 1[b]	...	...	...	...	...	...	...	...	...	...	...	...	...	...

[a] Prepared at National Bureau of Standards. See reference 1.
[b] Square bar.

drical rods of cold-drawn 0.12 and 0.57 per cent carbon steels were given additional cold work by being extended in a tension machine until they began to contract locally. A series of specimens were thus obtained in an approximately uniform, cold-worked condition from sections of each rod away from the necked portion. The results obtained with these steels were supplemented with results obtained with a few other carbon steels and some alloy steels. Comparison is also made with results obtained with non-ferrous metals.

TABLE II.—HEAT TREATMENT.

Material	Designation	Temperature, deg. Fahr.	Time Held, hr.	Cooled in	Temperature, deg. Fahr.	Time Held, hr.	Cooled in
High-purity iron	DB-17	1700	1	Furnace			
0.029% carbon steel	AF-17	1700	½	Furnace			
0.11% carbon steel	CA-16.5	1650	1	Furnace			
0.12% carbon steel	AG-17	1700	1	Furnace			
0.12% carbon steel	AG-W-9	1700	1	Water	900	1	Air
0.20% carbon steel	T-W-9	1625	1	Water	900	2	Air
0.23% carbon steel	AH-16.5	1650	1	Furnace			
0.42% carbon steel	CE-15.5	1550	1	Furnace			
3.3% nickel steel	Z-14.7	1475	5/6	Furnace			
3.3% nickel steel	Z-0-10	1475	½	Oil	1000	1	Air
13% Cr, 2% Ni steel	E-12.4	1240^a		Furnace			
17% Cr., 2% Ni steel	AZ-A-13.5	1750	¾	Air	1350	1½	Furnace
Cr-Ni-Mo steel	AS-14.5	1450^a		Furnace			
Copper	N-8	800	5				
Copper-tin alloy	BA-12	1200	½				
Brass	B-12	1200	½				
Monel metal	G-14	1400	1	Water			
Nickel	CW-14	1400	1	Air			

[a] Heat treated by manufacturer.

All the metals were in the form of round rods. A description of the metals is given in Table I and details of heat treatment are given in Table II. For a description of the apparatus and method of testing, especially at low temperatures, reference may be made to a previous paper (**6**).

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INFLUENCE OF NOTCH ANGLE AND ROOT RADIUS ON STRENGTH AND DUCTILITY OF STEELS AT VARIOUS TEMPERATURES

The Transverse Radial Stress and Stress Concentration Induced by a Notch, and Their General Effects on Mechanical Properties:

Figures 1 to 8 show the influence of the notch angle and the root radius on the yield stress, ultimate stress, breaking stress, and ductility of four carbon steels at various temperatures. These illustrations are of two types, which are arranged in pairs for convenient correlation. Figures 1, 3, 5, and 7 show the influence of notches on yield stress, ultimate stress, and breaking stress.[6] Each curve shows the influence of the notch angle (ω) on ultimate stress or breaking stress, for the indicated constant root radius (r). No curves of variation of the yield stress are shown, because this stress was not accurately revealed when the notch angle was less than about 120 deg. Comparison of the curves in a diagram reveals the influence of the root radius. The ultimate stress values represented are nominal stresses, that is, stresses based on the original area of the minimum cross-section. Breaking stresses are mean values based on the area of cross-section after fracture. When fracture occurred before the load reached a true maximum, the nominal stresses are indicated by the same symbols that are used for ultimate stresses, but the "prematurity" of the fracture is also indicated.

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[6] Values of ultimate stress are designated in these figures by open symbols, true breaking stresses by solid symbols. A separation of the upper and lower portion of the symbol representing yield stress indicates that corresponding values of the upper and lower yield stress were measured.

Figures 2, 4, 6, and 8 show the influence of notches on the relation between breaking stress and ductility. Ductility is expressed in terms of A_0/A, in which A_0 and A represent the initial and final areas of the minimum cross-section (**6**). As values of A_0/A are represented on a logarithmic scale, abscissas represent true strains. Each ascending broken line in Figs. 2, 4, 6, and 8 extends from a point whose ordinate represents the ultimate stress to a point representing the breaking stress and ductility. Each ascending line thus represents approximately the variation of the mean flow stress of a notched specimen between maximum load and fracture. Curves F represent the variation of the flow stress during the test of an unnotched specimen; curves F_0 represent qualitatively the variation of the unidirectional flow stress.

The course of a curve of yield stress or ultimate stress in Figs. 1, 3, 5, and 7 is the resultant of two opposing variables dependent on the notch angle. These variables are the radial stress ratio (S_3/S_1) and the stress concentration. Both the radial stress ratio and the theoretical (initial) stress concentration increase continuously with decrease in the notch angle, and this variation is qualitatively similar to the variation of the ultimate stress (Figs. 1, 3, 5, and 7). Moreover, the radial stress ratio and the initial stress concentration both increase with decrease in the root radius (**6–9**). Even slight plastic deformation, however, removes most of the concentration of longitudinal stress and thus reveals the influence of the radial stress ratio. The increase of the radial stress ratio with decrease of the notch angle tends to cause a continuous rise of a curve of yield stress or ultimate stress. Any concentration of longitudinal stress remaining at yield or at highest load, however, decreases the mean stress, and thus opposes the rise of a curve of yield stress or ultimate stress.

The course of a curve of breaking stress in Figs. 1, 3, 5, or 7 is the resultant of three variables dependent on the notch angle. Two of these are the same variables that affect the ultimate stress. The third variable is the ductility, which decreases continuously with decrease in the notch angle. The continuous increase in the radial stress ratio with decrease in the notch angle tends to cause a continuous rise of a curve of breaking stress, but any concentration of longitudinal stress at fracture tends to depress this curve. The continuous decrease of ductility tends to cause a continuous descent of a curve of breaking stress.[7] Any rise of a curve in Figs. 1, 3, 5, and 7, therefore, reveals a dominant influence of the radial stress ratio.

In Figs. 2, 4, 6, and 8, each curve of variation of the breaking stress is qualitatively similar to those in the corresponding Figs. 1, 3, 5, and 7, in that each curve rises from P_0 under the dominant influence of the increasing radial stress ratio, but eventually descends under the dominant influence of one or both of the other variables (increasing stress concentration and decreasing ductility). Each flow stress line also is influenced by the relative magnitudes of the radial stress ratio and the stress concentration. With decrease in the notch angle, the curve of flow stress is elevated because of the dominant influence of the increasing radial stress ratio. When the angle is decreased below a certain value, however, the influence of the increasing stress concentration prevents further elevation of the flow stress line. The continuous decrease in ductility, caused by the increase of the radial stress ratio and the stress concentration, moves the point representing fracture downward along the flow-stress line.

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[7] As shown in previous papers (**4–9**), plastic extension causes a continuous increase in the technical cohesive strength, and thus tends to cause an increase in any specific technical cohesion limit. A decrease in the total deformation at fracture would have the opposite effect.

If it were possible to obtain a quantitatively correct measure of the ductility (page 18 of reference **6**) and if no concentration of longitudinal stress existed at fracture, the course of a curve of breaking stress in a diagram of the type shown in Figs. 2, 4, 6, and 8 would depend on only one factor, the radial stress ratio. The relation between breaking stress and ductility, as affected by varying the radial stress ratio, would then be represented by a single curve. Curve L, the ideal locus of fractures, represents qualitatively the variation of the true ductility and true breaking stress with variation of the radial stress ratio.

The Tensile Properties of Carbon Steels as Affected by Notches and by Low Temperature:

Attention will be given first to three pairs of correlated diagrams in Figs. 1 to 6, the pairs representing results obtained at room temperature. With decrease in the notch angle, the curves of ultimate stress (Figs. 1(a), 3(a), and 5(a)) rise continuously because of the increasing radial stress ratio. Near the top, however, these curves are depressed somewhat by the increasing stress concentration. The breaking stress curves in these diagrams and in the correlated diagrams (Figs. 2(a), 4(a), and 6(a)) rise from P_0 because of the increasing radial stress ratio. After the initial rise, however, the depressing influences of the decreasing ductility and the increasing stress concentration manifest themselves in varying degree. For the annealed 0.11 per cent carbon steel (Figs. 1(a) and 2(a)), the influence of these two variables nearly counterbalances the influence of the radial stress ratio, and thus causes the curves of breaking stress to take a nearly horizontal course from the end of the initial rise to the point where the curves turn downward under the combined influence of the decreasing ductility and increasing stress concentration. For the annealed 0.42 per cent carbon steel (Figs. 5(a) and 6(a)), the decreasing ductility causes a dip in the breaking stress curve after the initial rise. As the ductility decreases, however, its variation diminishes and the influence of the radial stress ratio again elevates the curve. Finally the decreasing ductility and increasing stress concentration become dominant and the curves turn downward. Because of stress concentration, the breaking stress curves obtained with 0.01-in. root radius descend below the curves obtained with 0.03-in. radius (Figs. 1(a), 2(a), 5(a), and 6(a)). For the same reason, the curve of ultimate stress for 0.42 per cent carbon steel with 0.01-in. radius is lower than the curve obtained with 0.03-in. radius (Fig. 5(a)).

The influence of prior cold work is revealed by comparison of Figs. 1(a) and 2(a) with Figs. 3(a) and 4(a). Because the prior cold work given to the 0.12 per cent carbon steel CBM has diminished the influence of the ductility on the breaking stress curves in Figs. 3(a) and 4(a), the elevating influence of the increasing radial stress ratio predominates throughout most of these curves. If the 0.12 per cent carbon steel CBM differed from the 0.11 per cent carbon steel CA-16.5 only in the prior cold work, the unnotched specimens of these two steels would have about the same breaking stresses, and points P would be at about the same heights in Figs. 1(*a*) and 2(*a*) as in Figs. 3(*a*) and 4(*a*). The curves of breaking stresses for the cold-worked steel, however, would take the higher course (as they do in Figs. 3(*a*) and 4(*a*)), and the disruptive stress (T_1) would be greater for the cold-worked than for the annealed steel.

At low temperatures (diagrams (*b*), (*c*), and (*d*) of Figs. 1 to 6) the influence of stress concentration becomes prominent in the curves of ultimate stress and in the curves of breaking stress. Stress concentration manifests itself in the descent of the curves as the notch angle is decreased below a certain value (diagrams (*b*), (*c*), and (*d*) of Figs. 1, 3, and 5), which tends to increase as the temperature is lowered. The descent of these curves at a decreasing rate is in accordance with the variation of the stress concentration with the notch angle. The stress concentration remaining at maximum load and at fracture, as well as the theoretical stress concentration, evidently increases at a decreasing rate. The *relative* values of the stress concentration and the radial stress ratio, determine the course of a curve. Increasing the notch radius for the purpose of diminishing the stress concentration, therefore, does not necessarily raise the breaking stress, even at "premature" fracture. For example, a curve for 0.08-in. radius may take a lower course than a curve for 0.05-in. radius (Fig. 3(*b*)), and a curve for 0.05-in. radius may take a lower course than a curve for 0.03-in. radius (Fig. 5(*c*)).[8]

For all these carbon steels at low temperatures (diagrams (*b*), (*c*), and (*d*) of Figs. 1 to 6), the breaking stress curves show no clear influence of stress concentration between P_0 and a point representing a certain notch angle, which ranges from 120 deg. at -78 C. to 150 deg. at -188 C. Throughout this part of a curve, the course depends almost entirely on the variation of the radial stress ratio and the associated variation of the ductility. As the notch angle is decreased below this limiting value, however, the influence of stress concentration manifests itself in the accelerated descent of the curves in diagrams (*b*), (*c*), and (*d*) of Figs. 2, 4, and 6. Although the notch angle at which stress concentration becomes prominent ranges only from about 120 deg. to 150 deg., the corresponding ductility decreases when the temperature is lowered from -78 C. to -128 C., and decreases to less than 1 per cent when the temperature is lowered to -188 C. At -188 C., this slight plastic deformation evidently was sufficient to eliminate most of the initially small concentration of longitudinal stress when the notch angle was 150 deg. or larger. With decrease of the notch angle below 120 deg. or even below 150 deg., however, the initial stress concentration becomes so great that it cannot be eliminated from these annealed or cold-worked carbon steels at low temperatures, although at room temperature most of the initial stress concentration can be eliminated when the notch angle is as small as 50 deg. (diagrams (*a*) of Figs. 1 to 6).

As the temperature of these steels is lowered, any nonuniformity of stress is less easily removed by plastic deformation, although the ductility of unnotched specimens does not decrease greatly until the temperature is lowered below -128 C.

Figures 7 and 8 show the influence of notches on the strength and ductility of a cold-worked 0.57 per cent carbon steel at room temperature. These diagrams show interesting variations in the relative influences of the radial stress ratio and stress concentration, and in their effects on the breaking stress curves. The curves of ultimate stress[9] rise, with decreasing notch angle, to heights that vary with the root radius (Fig. 7). The smaller the root radius, the greater is the height attained because of the greater radial stress ratio, in spite of the fact that the stress concentration also tends to increase with decrease in the root radius. The descent, however, begins first in the curve representing 0.01-in. radius and later in the curves representing larger root radii. The relative variations of the radial stress ratio and stress concentration are revealed more clearly in the curves of breaking stress (Figs. 7 and 8). These curves also show the influence of the third important variable, ductility.

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[8] The interrupted descent of the curves in Fig. 1 probably is due to the fact that when the notch angle was about 120 deg. fracture occurred just after the drop from the upper to the lower yield stresses.

The breaking stress curves obtained with 0.03 and 0.05-in. root radii practically coincide throughout their rise from P_0 to the points representing an angle of 120 deg. These curves then descend to a minimum, again rise, and finally descend. The initial rise of these curves is under the dominant influence of the increasing radial stress ratio, and this portion constitutes practically a single curve representing the influence of the radial stress ratio alone on the relation between breaking stress and ductility; the influence of stress concentration on this part of the curve is negligible. When the notch angle is decreased below about 120 deg., the influence of stress concentration becomes dominant. The curves, however, do not descend at an increasing rate, as they do in diagrams (*b*), (*c*), and (*d*) of Figs. 1 to 6; the influence of the increasing radial stress ratio again becomes dominant, but the stress concentration finally dominates as the notch angle is decreased below about 60 deg.

The curve obtained with 0.01-in. root radius diverges from the curves obtained with 0.03 and 0.05-in. root radii as the notch angle is decreased below about 150 deg. Although stress concentration causes the curve to take this lower course, this curve rises higher than the other curves because (with 0.01-in. radius) the influence of the radial stress ratio increased more rapidly than the influence of the stress concentration, with decrease in the notch angle. With decrease of the angle below 75 deg., however, the influence of the stress concentration finally dominates.

The curve obtained with 0.08-in. radius takes a lower course throughout than the other curves. Although the stress concentration is less with this notch than with those having the smaller radii, the radial stress ratio is also less, and the influence of the radial stress ratio evidently is less in relation to the influence of the stress concentration.

In Fig. 8, the depressing influence of stress concentration has caused the crumpling of the curves obtained with 0.03 and 0.05-in. root radii as the notch angle is decreased below about 120 deg. This crumpling is due not only to depression of the entire flow stress lines obtained with notch angles less than 120 deg. but also to movement of the points representing fracture downward along the flow stress lines. Ductility thus is decreased not only by the increase of the radial stress ratio but also by the increase of the stress concentration. If the radial stress ratio could be increased from zero to 1.0 without concentration of longitudinal stress, the breaking stress probably would vary approximately as indicated in Fig. 8 by curve L, and the disruptive stress would be represented approximately by T_1.

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[9] The term "ultimate stress" is generally applied to the nominal stress when the load reaches a true maximum. The term, however, is here used with broader significance to designate the nominal stress at highest load, even when the fracture is "premature."

It is worthy of note that with the widely varying notched specimens and widely varying ductilities represented in Fig. 8, the mean stresses at fracture were all higher than those obtained with an unnotched specimen. With many of the notched specimens, the mean stresses at yield were much greater than the mean stress in an unnotched specimen at fracture. Similar results were obtained with the other cold-worked steel at room temperature (Fig. 4 (*a*)) and with the annealed steels at −188 C. (Figs. 2 (*d*) and 6 (*d*)). With the annealed 0.42 per cent carbon steel (Fig. 6 (*d*)) all but one of the notched specimens gave breaking stresses higher than that of the unnotched specimen: this diagram, therefore, shows the influence of transverse radial stress in raising the technical cohesion limit above the value for unidirectional tension.

TECHNICAL COHESIVE STRENGTH OF CARBON STEELS AS AFFECTED BY LOW TEMPERATURE AND BY PLASTIC DEFORMATION

When S_2 is kept equal to S_3, the strength of a metal may be represented by a diagram with axial stresses as ordinates and radial stresses as abscissas. Diagrams of this type have been shown in the previous papers (**4–9**). Diagrams of the same type for a low-carbon steel are shown in Figs. 9 and 10. These diagrams are assumed to be free from the distorting influence of stress concentration; they are qualitative representations of the strength of this steel in terms of ***uniform*** axial and radial stresses. The values of S_3 used in constructing these diagrams cannot be obtained directly from the results of tests of notched specimens, but must be based on an empirical assumption of a linear variation of S_3/S_1 with the ultimate stress (**6, 7**).

Each of the radiating broken lines in Figs. 9 and 10 is the locus of points representing the indicated constant value of the radial stress ratio; line H is the locus of points representing polarsymmetric stress ($S_1 = S_2 = S_3$).

Each of the two subdivisions of Figs. 9 and 10 contains a diagram representing the strength of the annealed 0.11 per cent carbon steel CA-16.5 and a diagram representing the strength of the cold-worked 0.12 per cent carbon steel CBM. Each diagram contains a curve L representing the locus of fractures and a curve T representing approximately the *initial* technical cohesive strength (**4–9**). Three of the diagrams for the annealed steel (Figs. 9 and 10(*a*)) also contain a curve representing the yield strength. In Figs. 9 and 10(*a*), curve T for the annealed metal has been placed slightly below, and curve T for the cold-worked metal has been placed slightly above, the position that would be occupied by a curve of ultimate strength. These positions are thus correlated with the relative positions of the corresponding curves in Fig. 12, which will be described later. At −188 C. (Fig. 10(*b*)), curve T practically coincides with curve L.

If the two steels differed only in the amount of prior cold work, this difference would have practically no effect on the locus of fractures in Figs. 9 and 10(*a*) to the left of P_0. Prior cold work under any stress combination not involving transverse tension, however, would elevate curve L in the field of positive values of S_3, would elevate the entire curve T, and thus would move point T_1 upward along line H. Consequently, although the elevation of the curves for steel CBM above the curves for steel CA-16.5 is due partly to an inherent difference between the two steels, it is due largely to the prior cold work.

With decrease of the temperature of these steels (Figs. 9 and 10), the yield strength (curve Y) is raised more rapidly than the initial technical cohesive strength (curve T). The ductility is thus reduced and curve T approaches curve L; at -128 C., these two curves for the cold-worked steel practically coincide except at small values of the radial stress ratio; at -188 C., curves T and L for both annealed and cold-worked steels coincide almost entirely.

In the diagrams just discussed (Figs. 9and 10) the influence of plastic deformation manifests itself in its effect on the indices of strength, but plastic deformation is not represented directly. In the diagrams now to be considered (Fig. 11), abscissas represent plastic deformation and ordinates represent breaking stresses. The system of coordinates in these derived diagrams for annealed 0.11 per cent carbon steel, therefore, is the same as in the basic diagrams (Fig. 2). Moreover, the locus of fractures L in each diagram of Fig. 11 is identical with the ideal locus of fractures L in the corresponding diagram of Fig. 2. Each locus of fractures, therefore, is assumed to be free from the distorting influence of stress concentration and deformation gradient; it is a qualitative representation of the influence of combined axial and radial uniform stresses on the relation between breaking stress and ductility. Each diagram in Fig. 11 should be studied with reference to the corresponding diagram in Fig. 9 or Fig. 10.

As any point on a locus of fractures in Fig. 11 represents a cohesion limit corresponding to a specific value of S_3/S_1, it may be made the terminus of a curve of flow stress corresponding to that value of S_3/S_1. The only flow stress curves shown in Fig. 11, however, are curves F_0, which represent unidirectional flow stress ($S_3/S_1 = 0$). A series of curves of variation of cohesion limits, however, is shown in each diagram. The left ends of the curves are in proper correlation with corresponding points on curves T in Figs. 9 and 10. Below each curve of cohesion, a corresponding curve of flow stress could be constructed, so that the two curves would rise and intersect at a small angle, as do curves F_0 and T_0. The ductility of the metal for a specific stress combination depends on the difference between the initial flow stress and the initial technical cohesion limit for the same stress combination. Thus the ductility for unidirectional tension would depend on the vertical distance between curves F_0 and T_0 at the origin, not on the vertical distance between curves F_0 and T_1.

The indicated decrease of ductility with increase in S_3/S_1 and with decrease of temperature is generally much less rapid in Fig. 11 than in Fig. 2. This difference is due to the great difference in stress uniformity represented by the two figures. Although increase in the radial stress ratio causes great decrease in ductility, especially at low temperatures, the effect on ductility and breaking stress is greatly accentuated in the presence of stress concentration.

VARIATION OF THE STRENGTH AND DUCTILITY OF ANNEALED AND COLD-WORKED CARBON STEELS WITH TEMPERATURE

The previously discussed diagrams show the strength and ductility of annealed and cold-worked carbon steels at various temperatures (Figs. 1 to 6). To study the quantitative variation of these properties with temperature, results taken from Figs. 1 to 6 have been plotted as ordinates in Figs. 12 and 13, with abscissas representing the corresponding temperatures. Figure 12 shows the variation of the strength indices with temperature, and Fig. 13 shows the variation of ductility. The temperature scale is the same that has been used in previous papers (**7, 8, 10**). As temperatures in deg. Kelvin are plotted on a logarithmic scale, abscissas are proportional to the logarithm of the deg. Kelvin. The scale, therefore, is the same in principal as Kelvin's original thermodynamic scale. This scale has been used because it gives a linear relationship between temperature and the strength indices for various metals, except when structural changes occur within certain temperature ranges. As shown in Fig. 12, however, a linear relationship was not obtained with these carbon steels.

The most striking feature of the diagrams for the annealed steels (Fig. 12 (*a*) and (*c*)) is the great and rapidly accelerating rise of the curves of yield stress. At −188 C. the yield stress is nearly three times as great as at room temperature. The corresponding curves of ultimate stress for unnotched specimens also rise with increasing steepness, but the rise is much less rapid than that of the yield stress. At −188 C., fracture of these steels occurred just before the load reached a true maximum. If the curve of ultimate stress were prolonged to this temperature, it would be only slightly higher than the curve of yield stress. For the cold-worked steel (Fig. 12(*b*)), the curve of yield stress (not shown) would practically coincide with the curve of ultimate stress.

The breaking stress curves for unnotched specimens also rise at an increasing rate from room temperature to −128 C. With further decrease of temperature, however, they descend with reversal of curvature, reach a minimum, probably at a temperature a little above −188 C., and then resume their upward course. The rise of each breaking stress curve (Fig. 12) with decrease of temperature to −128 C. is accompanied by only a slight decrease of ductility (Fig. 13). The descent of each breaking stress curve between −128 C. and −188 C. (Fig. 12) is accompanied by a decrease of ductility almost to zero. This descent, therefore, is because of the dominant effect of the great decrease of ductility, not because of a decrease in the *initial* technical cohesive strength. The initial *technical cohesion limit* for unidirectional tension, represented qualitatively by curve T_0, rises continuously with decrease of temperature to −188 C. With decrease of temperature slightly below −188 C., the steel would become completely brittle, but the technical cohesive strength would continue to rise, as indicated qualitatively by the projection of curve T_0.

Each curve for notched specimens (Fig. 12) rises at an increasing rate with decrease of temperature to a certain value dependent on the notch angle; the curve then descends, first at an increasing, then at a decreasing rate. The smaller the notch angle, the higher is the temperature at which this descent begins. Comparison of Fig. 12 with Fig. 13 shows that the ductility of a notched specimen generally decreases appreciably before the descent of the curve in Fig. 12 begins. Comparison of Fig. 12 with Figs. 2, 4, and 6, shows that the abrupt descent of the curves in Fig. 12 must be attributed chiefly to the influence of increasing stress concentration on the breaking stress. The increase of stress concentration with decrease of temperature is caused by the decrease of ductility. At some temperature below −188 C., however, the metal would become completely brittle, and the breaking stress curve for a notched specimen would reach a minimum. With further decrease of temperature, the curve would be expected to rise because of the increasing technical cohesive strength.

In Fig. 13, the curves of variation of

ductility with temperature are qualitatively similar to a curve of variation of the resistance to impact of notched specimens. The smaller the notch angle, the higher is the temperature of the steepest descent of the curve. If curves could be constructed to represent selected constant values of S_3/S_1, without stress concentration, they would be qualitatively similar to the curves in Fig. 13, but the accentuating effect of stress concentration on ductility would be absent.

INFLUENCE OF COMPOSITION AND HEAT TREATMENT ON THE VARIATION OF THE STRENGTH AND DUCTILITY OF METALS WITH TEMPERATURE

For further study of the factors involved in the embrittling effect of low temperature on steels, the results obtained with the previously discussed carbon steels (Fig. 12) will now be compared with results obtained with non-ferrous metals and with steels differing in composition and heat treatment (Figs. 14, 15, and 16).

Figure 14 shows the variation of the yield stress, ultimate stress, and breaking stress of unnotched specimens of three non-ferrous metals and a 13 per cent chromium, 2 per cent nickel steel. The brass and the alloy steel were tested only in the fully softened condition; the copper-tin alloy and monel metal were tested both in annealed and in cold-worked condition. The strength indices for each of these metals vary linearly with temperature, on this scale, except when structural changes such as strain aging occur near the upper end of the temperature range. The straight portion of each yield stress line for an *annealed metal* points approximately to zero stress at the melting point. The breaking stress line is practically the same for both the annealed and the cold-worked metals. A linear relationship such as that shown in Fig. 14 probably exists whenever the variation of strength is due to temperature alone, not to a combined influence of temperature and structural change.

The variation of the strength indices of these non-ferrous metals and of 13 per cent chromium, 2 per cent nickel steel with temperature (Fig. 14) differs greatly from the curvilinear variation of the strength indices of the carbon steels (Fig. 12). The greatest difference is in the variation of the yield stress. Whereas the yield stress of the annealed carbon steels is nearly tripled and the yield ratio (ratio of yield stress to ultimate stress) is nearly doubled, when the temperature is lowered from room temperature to −188 C., the yield stress of the metals represented in Fig. 14 is increased only 50 to 75 per cent, and the yield ratio is practically unchanged. Another great difference between these two groups of metals is in the variation of the ductility. With decrease of the temperature, the ductility (not shown here) of each of the non-ferrous metals either remains unchanged or increases. The ductility of the 13 per cent chromium, 2 per cent nickel steel decreases considerably, but unnotched specimens retain considerable ductility even at −188 C. The loss of ductility with decrease of temperature is much less for this steel (Fig. 17(*a*)) than for the carbon steels (Fig. 13).

The initial technical cohesive strength of each of the non-ferrous metals represented in Fig. 14 probably increases linearly with decrease of temperature. The variation of the cohesion limit for unidirectional tension would be represented by a straight line, such as lines T_0 in Fig. 14, not far from the line of variation of the ultimate stress. As the ductility depends on the vertical difference between such a line and the yield stress line, and as the two lines would not converge with decrease of temperature, the ductility would not be expected to decrease. In Fig. 12, however, lines Y and T_0 converge at a rapidly increasing rate with decrease of temperature, and thus account for the great decrease in ductility. Moreover, the greater the radial stress ratio, the more rapid would be the convergence of the corresponding lines of yield stress and initial technical cohesion limit, and the higher would be the temperature at which the decrease in ductility would be most rapid.

Figure 15 shows the influence of the composition and heat treatment of steels on the variation of strength with temperature. The steel represented in Fig. 15(*a*) contained titanium, which had been added by the manufacturers in order to eliminate the discontinuity of the stress-strain curve at the yield point. The tests by the authors showed no drop of the beam at room temperature or at −78 C., but a slight drop at −188 C. The addition of titanium, however, has not appreciably affected the course of the yield stress curve in Fig. 15(*a*). The yield stress was about $4\frac{1}{2}$ times as great at −188 C. as at room temperature. This ratio is about the same as the ratio found by two of the authors for ingot iron (Fig. 21 of reference 7). With annealed high-purity iron (DB-17), the authors found the yield point at −188 C. to be 82,000 psi., whereas Cleaves and Hiegel (1) found the yield point of a comparable specimen at room temperature to be about 8400 psi. The ratio between the values for these two temperatures, therefore, is nearly 10. The ratio evidently increases with the purity of the iron.

The ultimate stress of the titanium-bearing iron at −188 C. practically coincides with the breaking stress (Fig. 15 (*a*)). The ingot iron and the high-purity iron broke before the load quite reached a true maximum. No breaking stress values could be obtained with the titanium-bearing iron at −78 C. and at room temperature because the very ductile specimens continued to extend at the rim after fracture started near the axis.

Figure 15(*b*) and (*c*) shows the influence of heat treatment on the strength indices for two low-carbon steels. Each steel was tested in the annealed condition and in a quenched-and-tempered condition. The quench-temper treatment has raised the curves of yield stress and ultimate stress above the corresponding curves for the annealed steels. The yield stress curve has thus been raised relatively much more at room temperature than at −188 C., but the ultimate stress curve has been raised almost equally at these two temperatures. The convergence of corresponding curves of yield stress and ultimate stress with decrease of temperature, therefore, is less rapid for the quenched-and-tempered steels than for the annealed steels. As a curve for the initial technical cohesion limit T_0 would be near and almost parallel to the corresponding curve of ultimate stress (Fig. 15(*b*) and (*c*)), the convergence of curves T_0 and Y would be less rapid for the quenched-and-tempered than for the annealed steel. Consequently, because (as already shown) the ductility depends on the difference between the initial technical cohesion limit T_0 and the yield stress, the decrease of ductility with decrease of temperature would be expected to be less rapid for the quenched-and-tempered carbon steels than for the annealed steels. A comparison of the ductilities of steels after these two heat treatments is given in Fig. 17.

Figure 17(*b*), (*c*), and (*d*) shows the influence of temperature on the ductilities of three carbon steels in the annealed condition and in the quenched-and-tempered condition. The steels represented in diagrams (*b*) and (*c*) are the same as those represented in Fig. 15(*b*) and (*c*). Moreover the steel represented in Fig. 17 (*d*) differs little in carbon content from the steel represented in Fig. 13(*a*). As shown in Fig. 17(*b*), (*c*), and (*d*), the quench-temper treatment has greatly increased the ductility of these three carbon steels at −188 C. As shown in Fig. 15 (*b*) and (*c*), the quench-temper treatment has also increased the breaking stress at −188 C. However, if the breaking stress curve in Fig. 15(*b*) could be extended to temperatures below −188 C., it probably would descend with reversal of curvature as does the curve for annealed steel. For the 0.2 per cent carbon steel T-W-9 (Fig. 15 (*c*)), the ductility at −188 C. evidently was enough to permit the curve of breaking stress to continue its rise with decrease of temperature to −188 C.

Figure 15(*d*) shows the effect of heat treatment on the variation of the strength indices of a nickel steel. The effect of heat treatment is qualitatively similar to its effect on carbon steels. The quench-temper treatment raised the yield stress, above that of the annealed steel, much more at room temperature than at −188 C. The ratio of the yield stresses corresponding to the two heat treatments is 2 at room temperature, but only 1.5 at −188 C. Consequently, the curves of yield stress and ultimate stress for the annealed steel converge with decrease of temperature, but the curves for the quenched-and-tempered steel diverge. For reasons previously given, therefore, the curve of breaking stress for the quenched-and-tempered steel would be expected to rise continuously with decrease of temperature to −188 C., as does the curve for the annealed steel. However, as the specimen tested at −188 C. broke at a flaw, the actual course of the curve below −128 C. has not been determined, but probably is as indicated by the extension of this curve in Fig. 15 (*d*). It would also be expected that the ductility at −188 C. would be greater for the quenched-and-tempered steel than for the annealed steel.

The effect of the alloying with nickel on the variation of the strength indices with temperature is revealed by a comparison of the diagram for the annealed nickel steel (Fig. 15(*d*)) with the diagrams for the annealed carbon steels. The yield stress at room temperature is nearly twice as great for the annealed nickel steel as for the annealed 0.12 and 0.23 per cent carbon steels (Fig. 15(*b*) and (*c*)), and is about 70 per cent greater than that of the annealed 0.42 per cent carbon steel (Fig. 12(*c*)). At −188 C., however, the yield stress of annealed nickel steel is only about 10 per cent greater than that of the annealed 0.12 and 0.23 per cent carbon steels, and is about equal to that of the 0.42 per cent carbon steel. The convergence of a curve of yield stress toward the curve of ultimate stress or toward a curve of variation of the initial severing stress (T_0), therefore, is much less rapid for the nickel steel than for the carbon steels. For this reason, the ductility of the annealed nickel steel (Fig. 17(*a*)) decreases much less rapidly with temperature than does the ductility of the annealed carbon steels (Figs. 17(*b*), (*c*), (*d*), and 13). Consequently, the breaking stress curve for the annealed nickel steel (Fig. 15(*d*)) does not descend between −128 and −188 C., but rises nearly linearly with decrease of temperature. A similar correlation exists between the curves of yield stress and ultimate stress for 13 per cent chromium, 2 per cent nickel steel (Fig. 14(*c*)), the curve of ductility of this steel (Fig. 17(*a*)), and the linear rise of the curve of breaking stress (Fig. 14(*c*)).

Even heat-treated carbon steels and alloy steels, however, show some loss of ductility with decrease of temperature.[10] In this respect, they differ from non-ferrous metals such as those represented in Fig. 14. The ductility of these non-ferrous metals, and probably the ductility of any metal that is free from structural change, does not decrease with decrease of temperature to −188 C. (7). The decrease of the ductility of the quenched-and-tempered carbon steels and the alloy steels decreases the slope of the straight lines of breaking stress, such as those in Figs. 14(*c*), 15(*c*), and 15(*d*). These lines are nearly parallel to the lines of ultimate stress, whereas the lines of breaking stress for the non-ferrous metals are much steeper than the lines of ultimate stress (Fig. 14(*a*), (*b*), and (*d*)).

The variation of the strength and ductility of iron and steels with decrease of temperature is anomalous. The normal variation of the strength of a metal, the variation due to temperature alone, probably is the linear variation shown in Fig. 14(*a*), (*b*), and (*d*). The ductility of a normal metal does not decrease with decrease of temperature to −188 C.; the ductility of some metals increases. The yield stress of annealed metal normally increases only about 75 per cent, and the line of variation of the yield stress points approximately to zero stress at the melting point. The yield stress line for annealed iron, annealed carbon steels, and low alloy steels, however, curves upward at both ends from the line representing the linear variation of yield stress of a normal metal (Fig. 15). At the high-temperature end, this upturn probably is due to strain aging, although the prevalent view is that strain aging does not affect the yield point. A similar structural change may also account for the upturn at the low-temperature end.

Figure 16 shows the influence of temperature on the yield stresses of various annealed ferrous and non-ferrous metals. Curves 1 to 4, reproduced from Figs. 12(*c*) and 15, show the variation of the yield stress for carbon steels with carbon content ranging from 0.02 per cent to 0.42 per cent. Comparison of curves 5 to 8 with curves 1 to 4 shows the influence of alloying elements, especially elements in solution in the ferrite. Strengthening the ferrite by alloying raises the yield stress much more at room temperature than at −188 C. The alloying thus decreases the curvature of the yield stress line, and decreases the departure of this line from the straight line pointing approximately toward zero stress at the melting point. For the highly alloyed steels (curves 6, 7, and 8), the lines of yield stress are practically straight. These lines, as well as the straight portions of the lines for the non-ferrous metals (Fig. 16(*b*) and (*c*)), point approximately to zero stress at the corresponding melting points.

THE EFFECT OF RATE OF STRAIN ON THE VARIATION OF THE MECHANICAL PROPERTIES OF STEELS WITH TEMPERATURE

Brittle fractures of structures in service become more prevalent as the temperature falls to near the freezing point of water. This temperature is considerably higher than the temperatures at which the fractures of notched tension test specimens become brittle (Figs. 12 and 13). This difference in temperature may be due at least partly to a difference in the rate of strain. The higher the strain rate, the higher is the temperature of the transition from ductile to brittle fracture of a notched specimen.

This effect of the strain rate has generally been attributed to a differential effect of the rate on the flow stress and the initial technical cohesive strength. According to the prevalent view, the initial technical cohesive strength increases very little with increase in the strain rate, and thus any metal would become brittle at a strain rate sufficiently high. There is scattered evidence, however, that the rate of strain generally affects an initial technical cohesion limit about as much as it affects the corresponding flow stress. The evidence indicates that increase of the strain rate even to nearly a million times the rate for an ordinary tension test generally causes no decrease of the ductility of either ferrous or non-ferrous metals, provided that the tests are made with unnotched specimens.

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[10] A slight differential effect of temperature on the curves of yield and initial severing stress (T_0) may have considerable effect on the variation of ductility with temperature because of the small angle between the corresponding curves of variation of flow stress and cohesion with plastic deformation (Fig. 11).

A recent paper of Manjoine (3) describes an investigation of the yield stress, ultimate stress and ductility of annealed mild steel throughout a range of strain rate from 10^{-6} to nearly 10^3 per second. The range of rates upward from that of an ordinary tension test was nearly a million to one. Throughout this range the yield stress increased from about 29,000 to 75,000 psi., and the yield ratio increased from about 0.5 to nearly 1.0. These increases, therefore, were nearly equal to the increases of the same properties with decrease from room temperature to −188 C. (Fig. 12). Additional evidence is needed to show what is the normal variation of the yield stress of metals with strain rate. The great increase of the yield stress for steels with increase of the strain rate may be as anomalous as the great increase of the yield stress with decrease of temperature. The effect of strain rate on the ductility of steels, however, evidently is not anomalous. Manjoine found the total elongation to be no less for a strain rate of 300 than for a rate of 10^{-3} per second. The evidence that the ductility does not decrease with increase in the strain rate implies that the strain rate affects the initial technical cohesive strength about as much as it affects the flow stress.

The effect of increase in the strain rate on the temperature at which cold brittleness appears, therefore, is not due to an elevation of the flow stress in relation to the corresponding initial technical cohesion limit, but is due to an effect on the stress concentration. An increase in the strain rate decreases the time available for relief of stress concentration, and thus has an effect qualitatively similar to a decrease of temperature. An increase in the strain rate, therefore, would move the steep descent of the curves of breaking stress and of ductility (Figs. 12 and 13) to higher temperatures.

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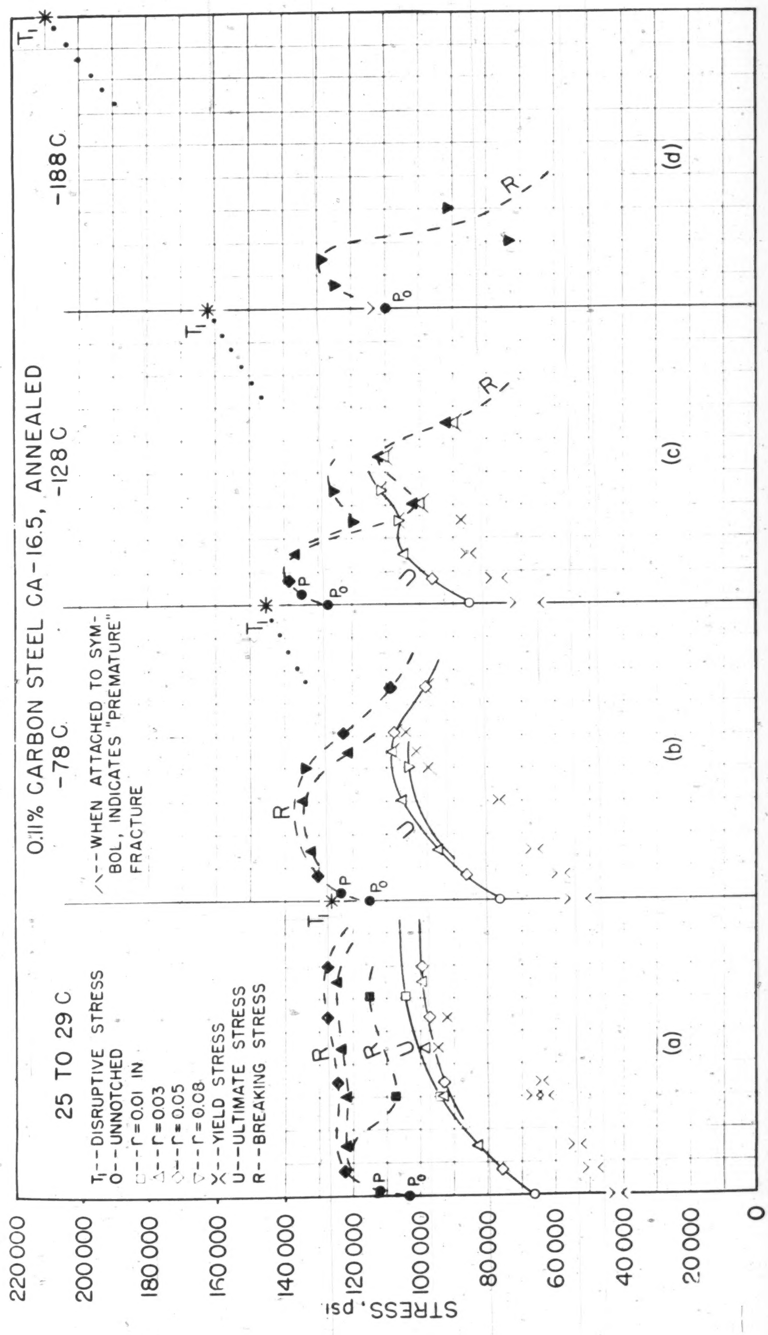

Fig. 1.—Influence of the Notch Angle on the Strength of Specimens of Annealed 0.11 per cent Carbon Steel at Four Different Temperatures.

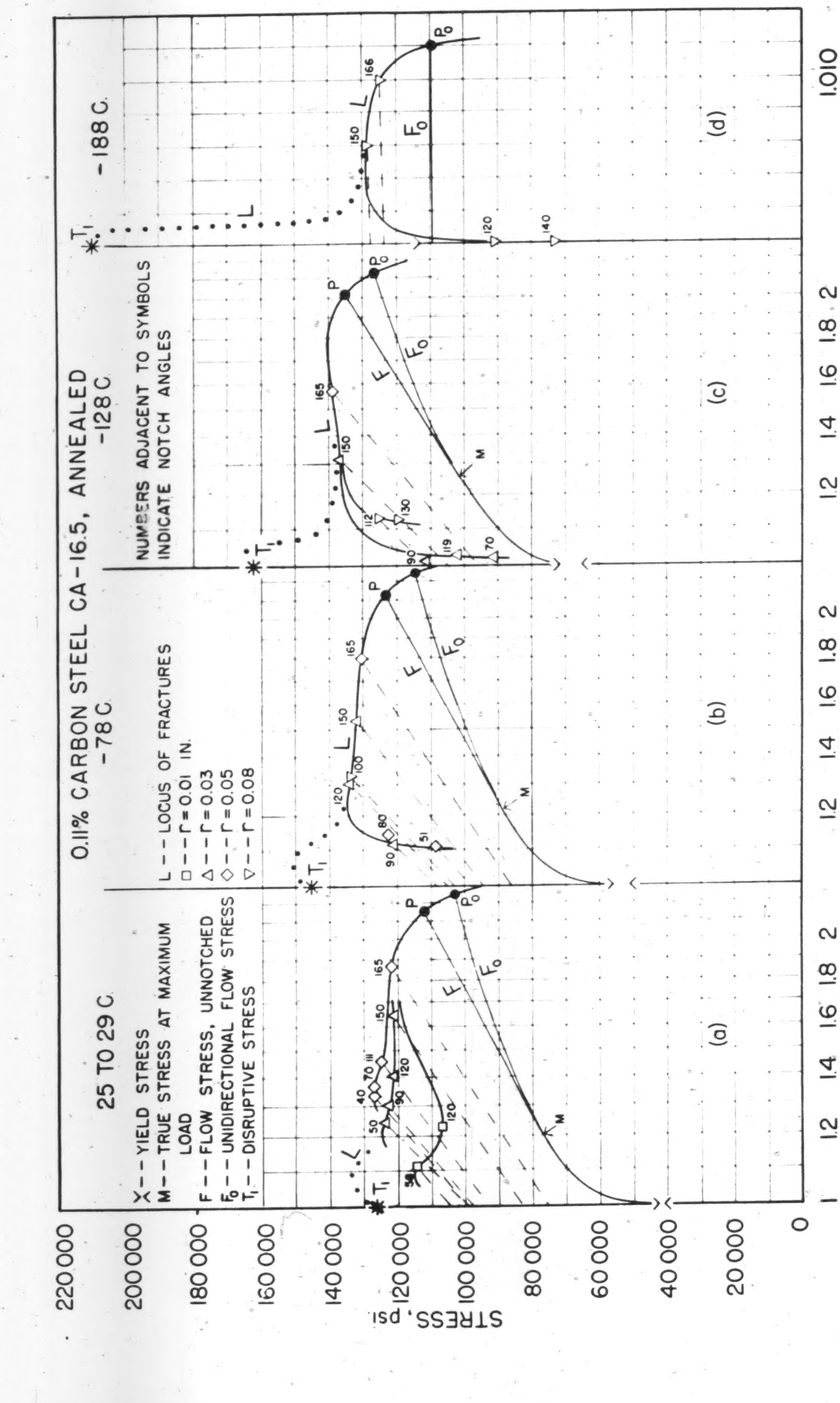

Fig. 2.—Influence of Notches on the Relation Between Breaking Stress and Ductility of Annealed 0.11 per cent Carbon Steel at Four Different Temperatures.

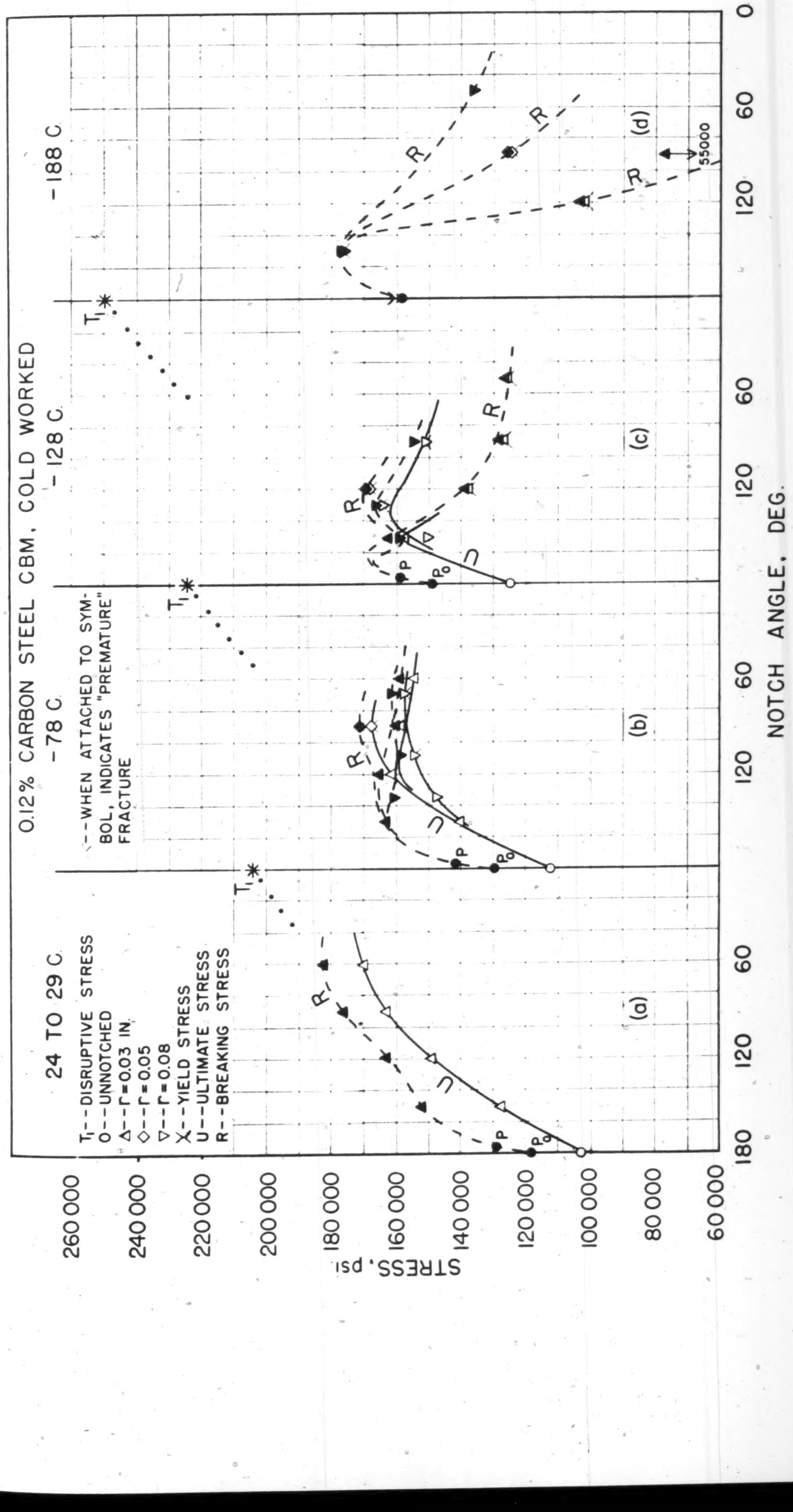

FIG. 3.—Influence of the Notch Angle on the Strength of Cold-Worked 0.12 per cent Carbon Steel at Four Different Temperatures.

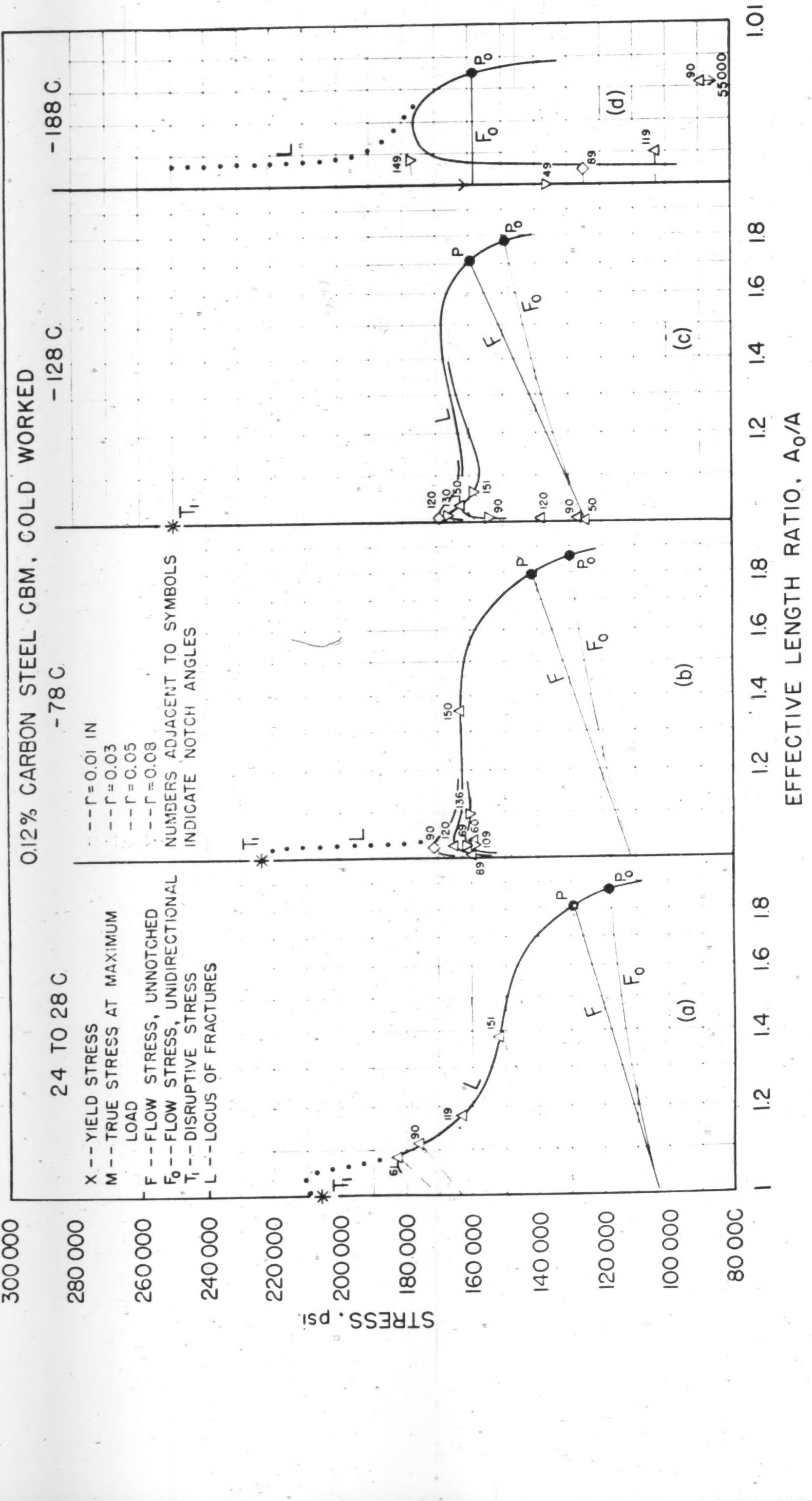

Fig. 4.—Influence of Notches on the Relation Between Breaking Stress and Ductility of Cold-Worked 0.12 per cent Carbon Steel at Four Different Temperatures.

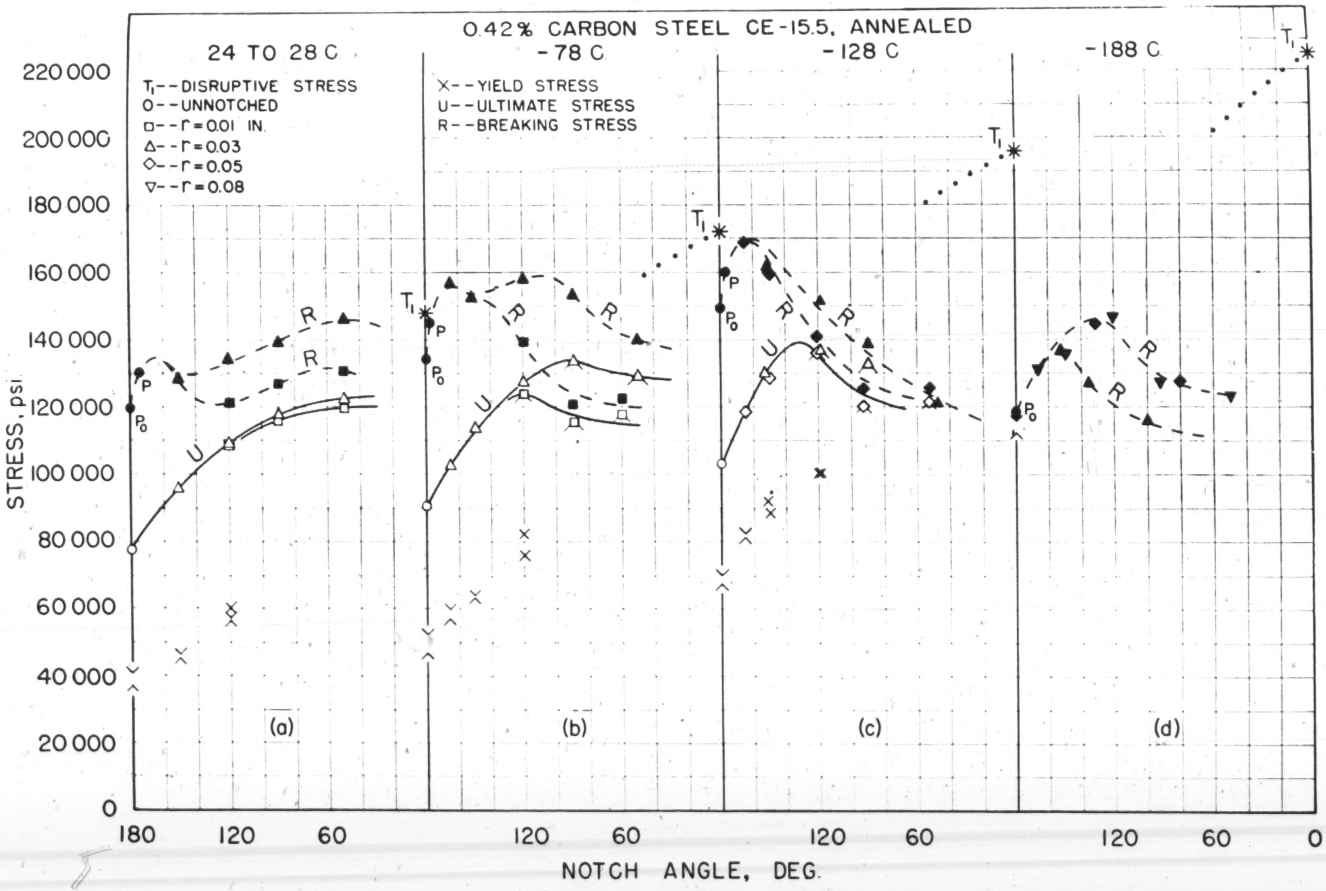

FIG. 5.—Influence of the Notch Angle on the Strength of Annealed 0.42 per cent Carbon Steel at Four Different Temperatures.

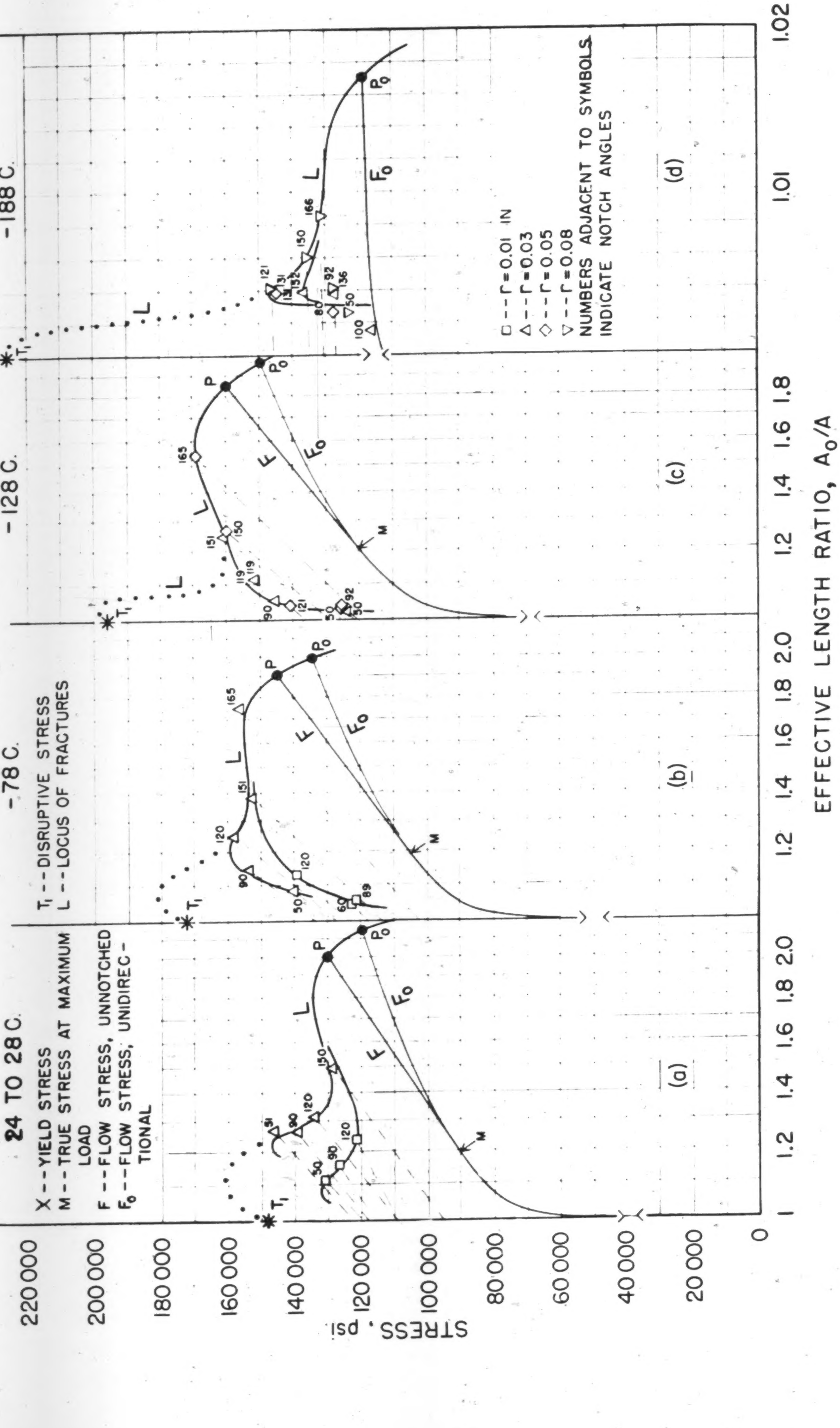

FIG. 6.—Influence of Notches on the Relation Between Breaking Stress and Ductility of Annealed 0.42 per cent Carbon Steel Different Temperatures.

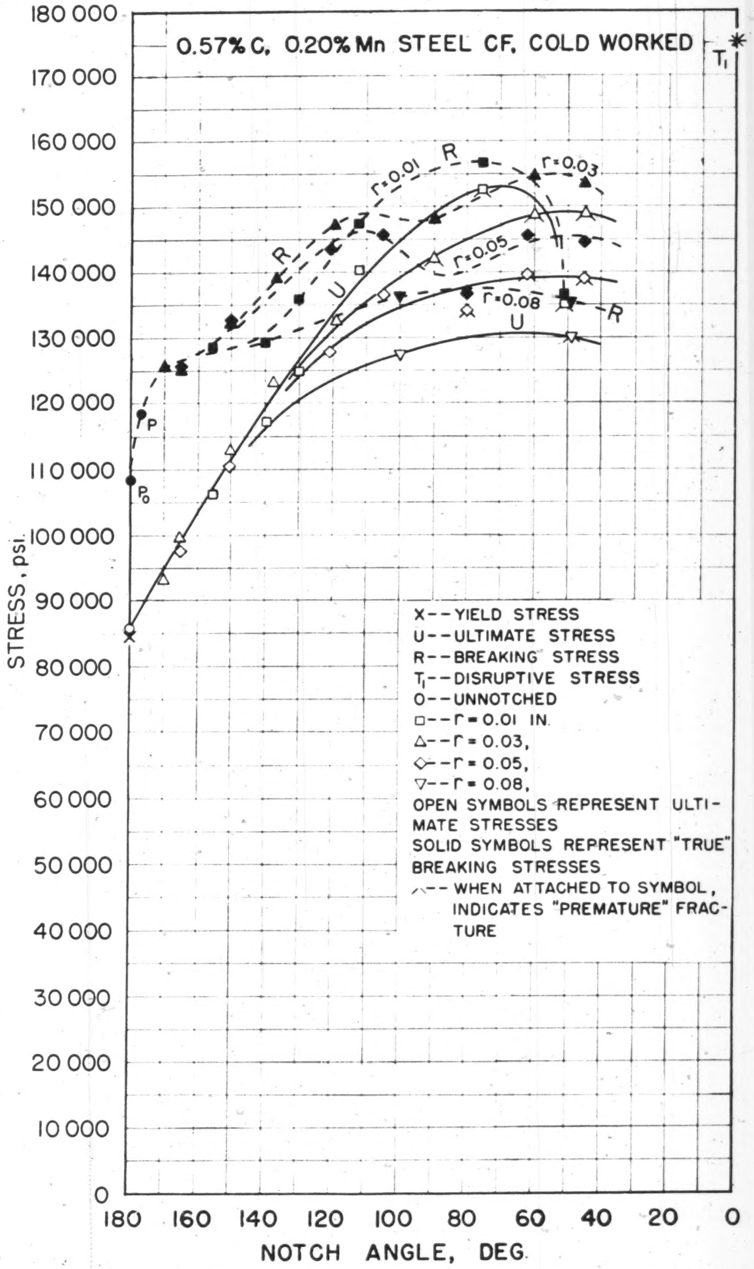

Fig. 7.—Influence of the Notch Angle and Root Radius on the Strength of Cold-Worked 0.57 per cent Carbon Steel at Room Temperature.

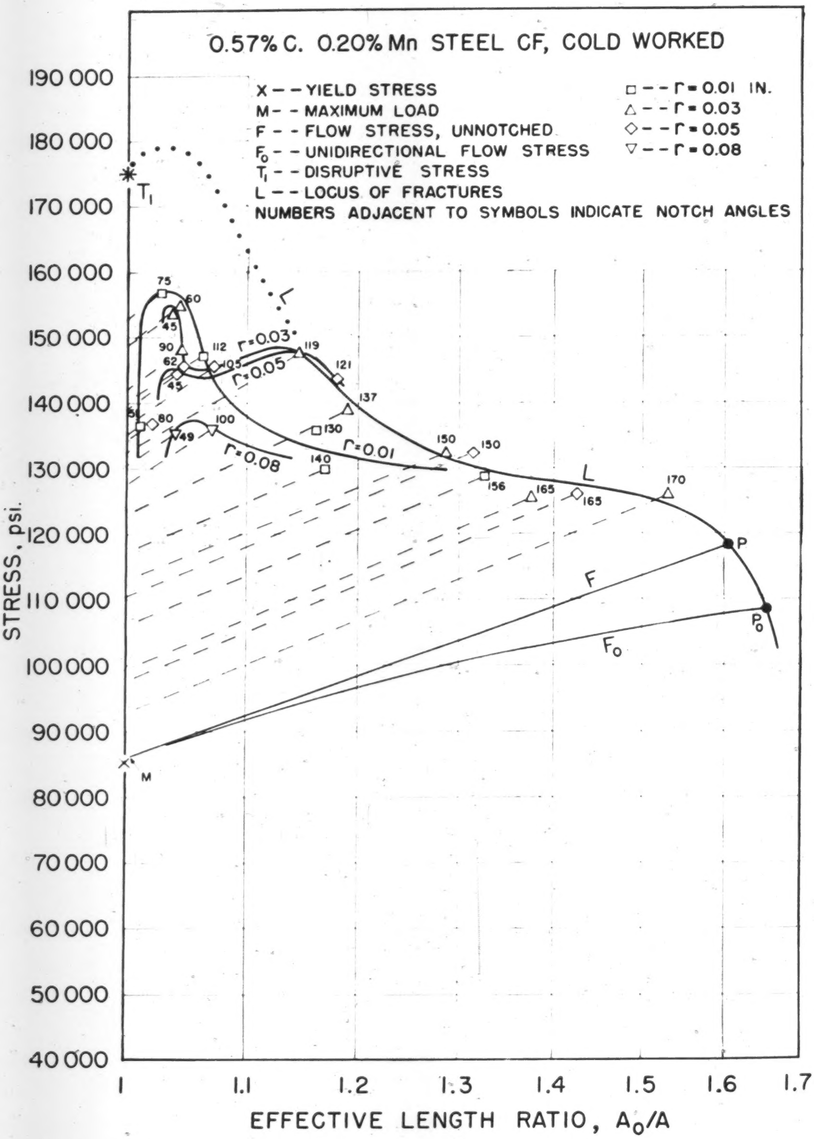

FIG. 8.—Influence of Notches on the Relation Between Strength and Ductility of Cold-Worked 0.57 per cent Carbon Steel at Room Temperature.

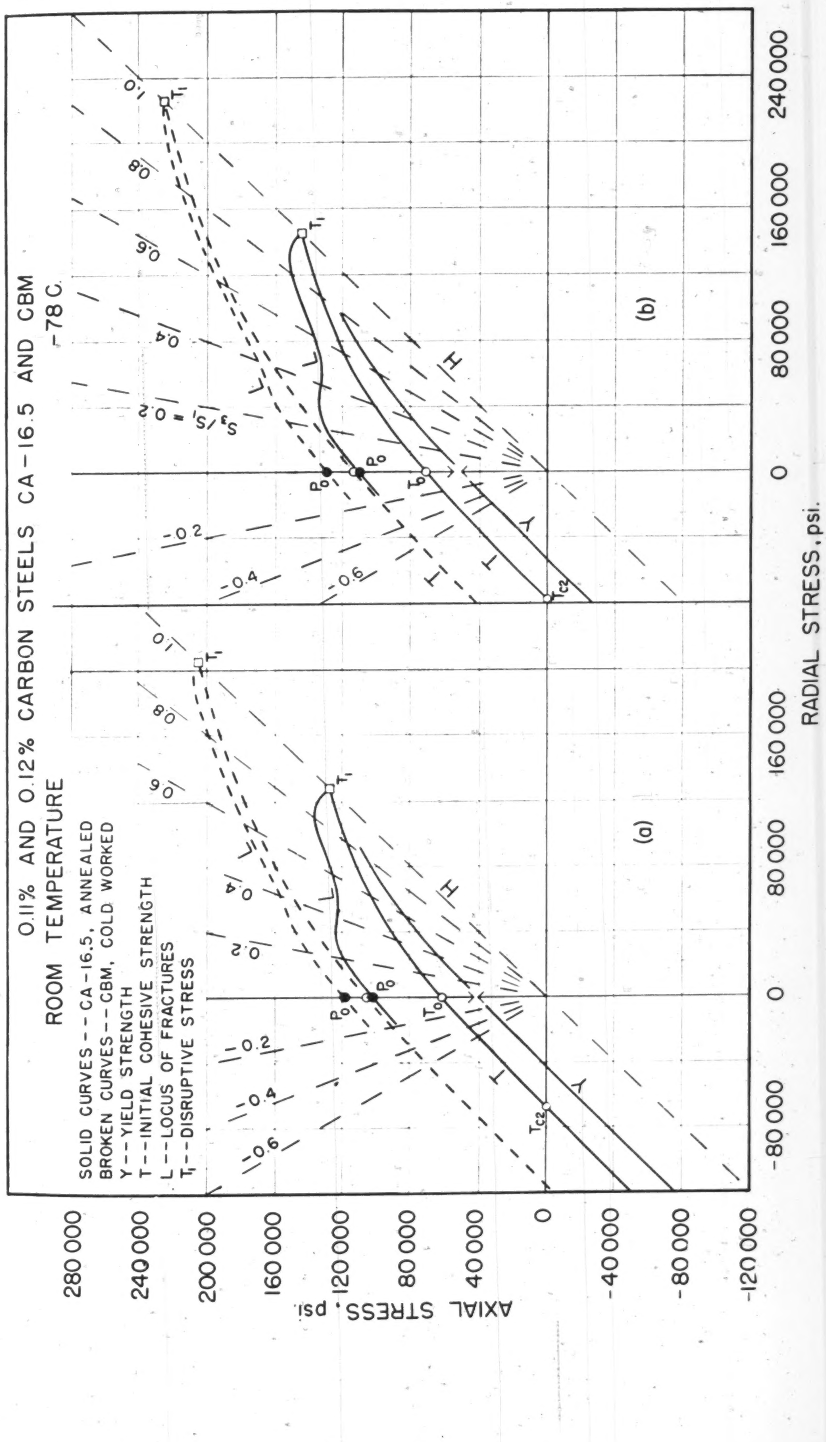

FIG. 9.—Influence of the Radial Stress Ratio on Yield Stress and Technical Cohesion Limit of Annealed and Cold-Worked Low Carbon Steels at Two Different Temperatures.

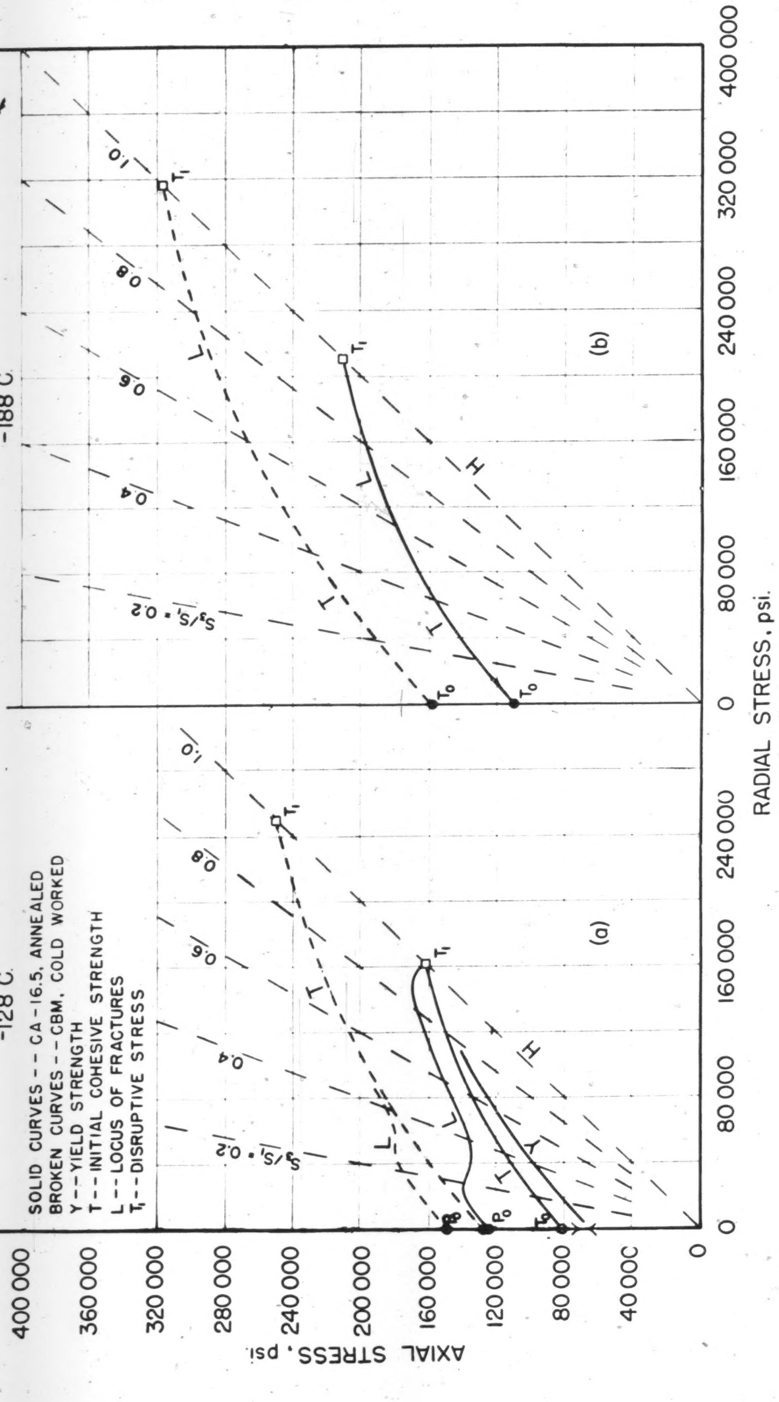

FIG. 10.—Influence of the Radial Stress Ratio on Yield Stress and Technical Cohesion Limit of Annealed and Cold-Worked Low Carbon Steels at Two Different Temperatures.

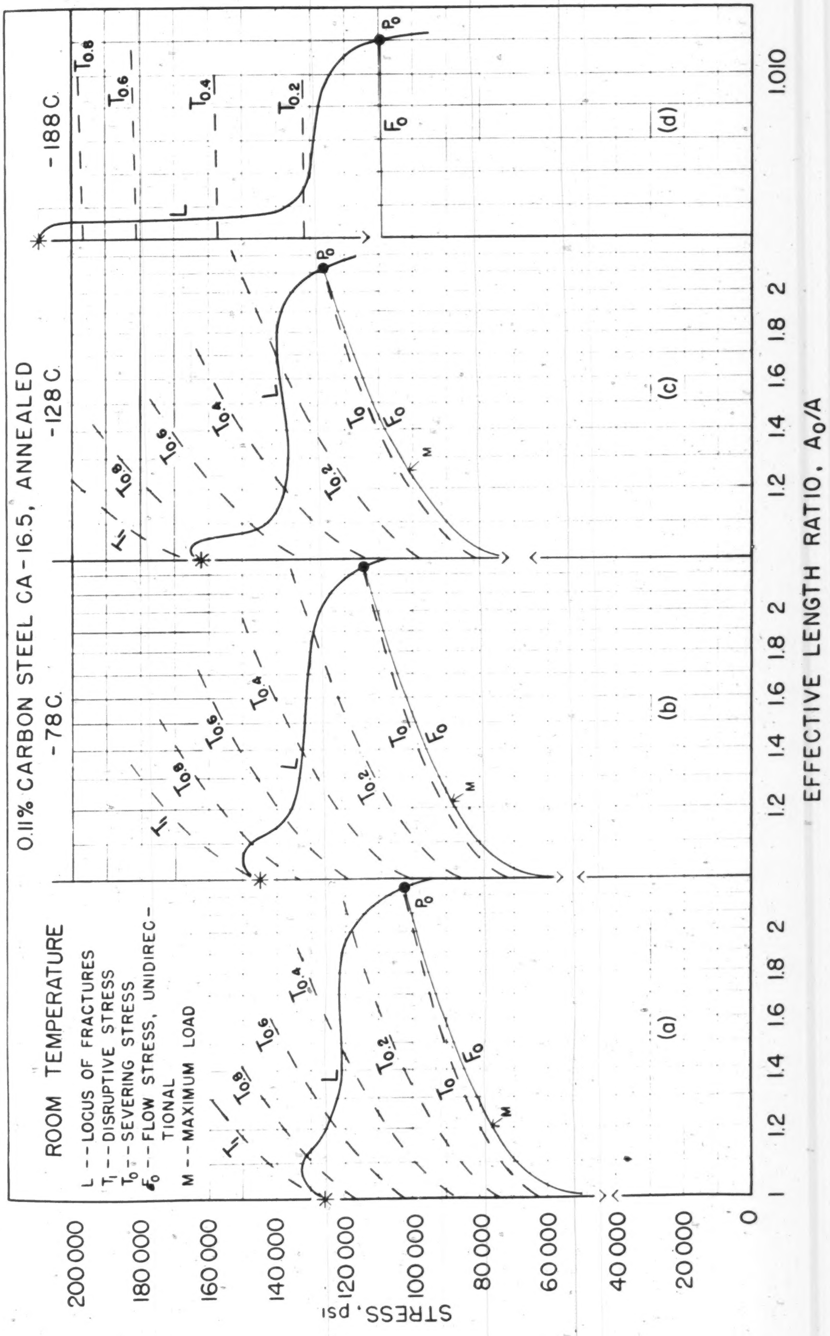

FIG. 11.—Influence of the Radial Stress Ratio on the Relation Between Breaking Stress and Ductility of Annealed 0.11 per cent Carbon Steel at Four Different Temperatures.

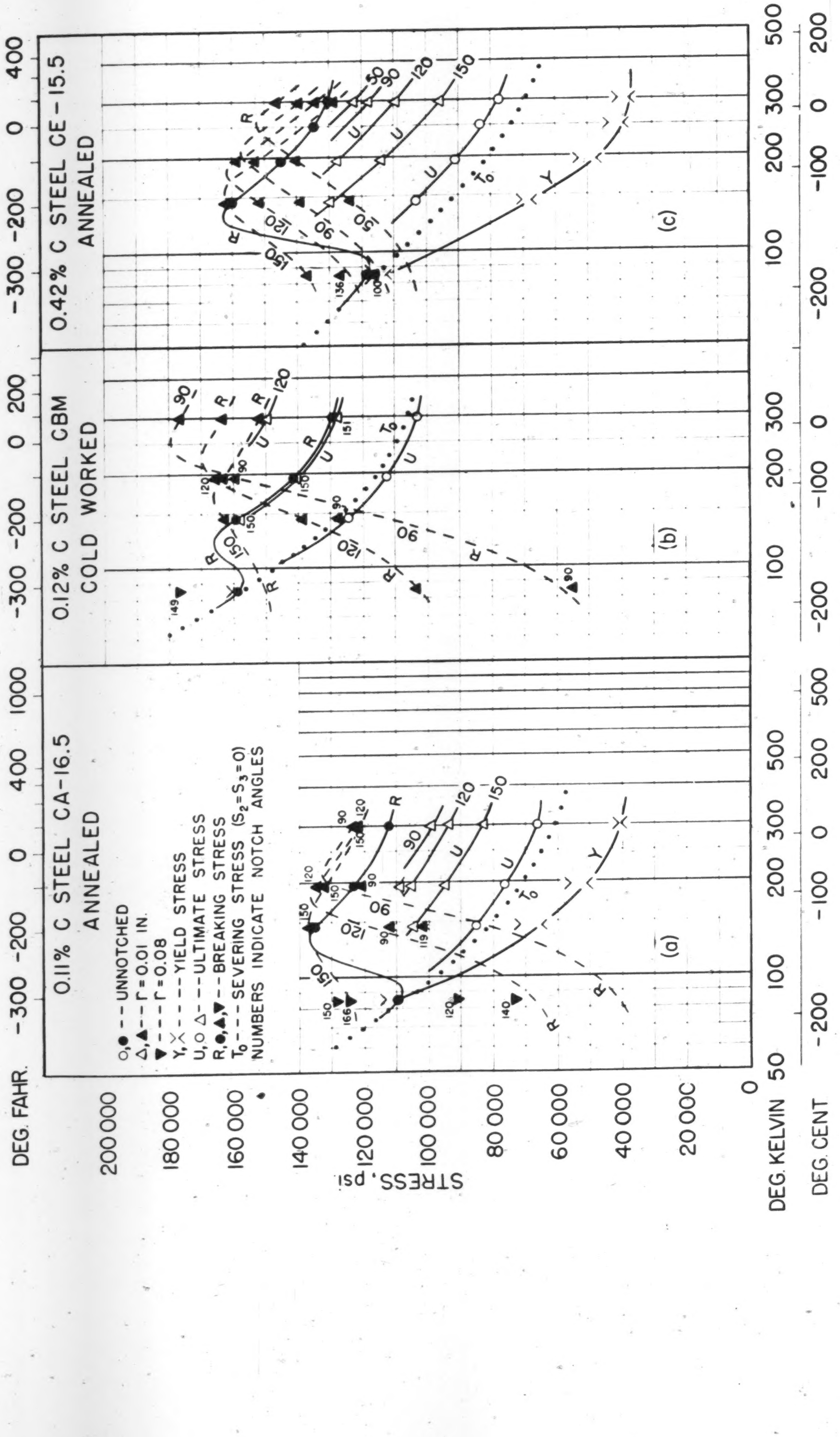

FIG. 12.—Variation of the Strength of Three Carbon Steels with Temperature.

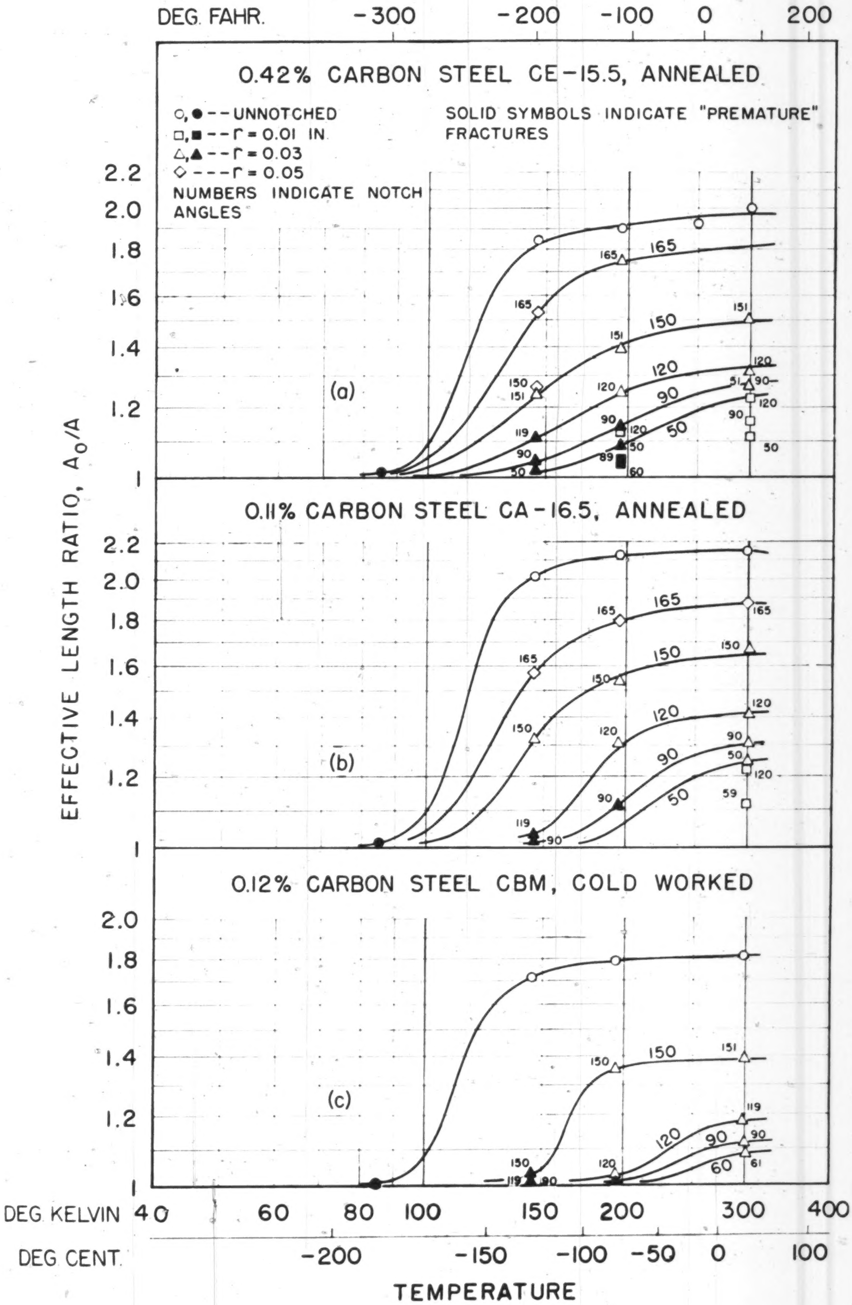

FIG. 13.—Variation of the Ductility of Three Carbon Steels with Temperature.

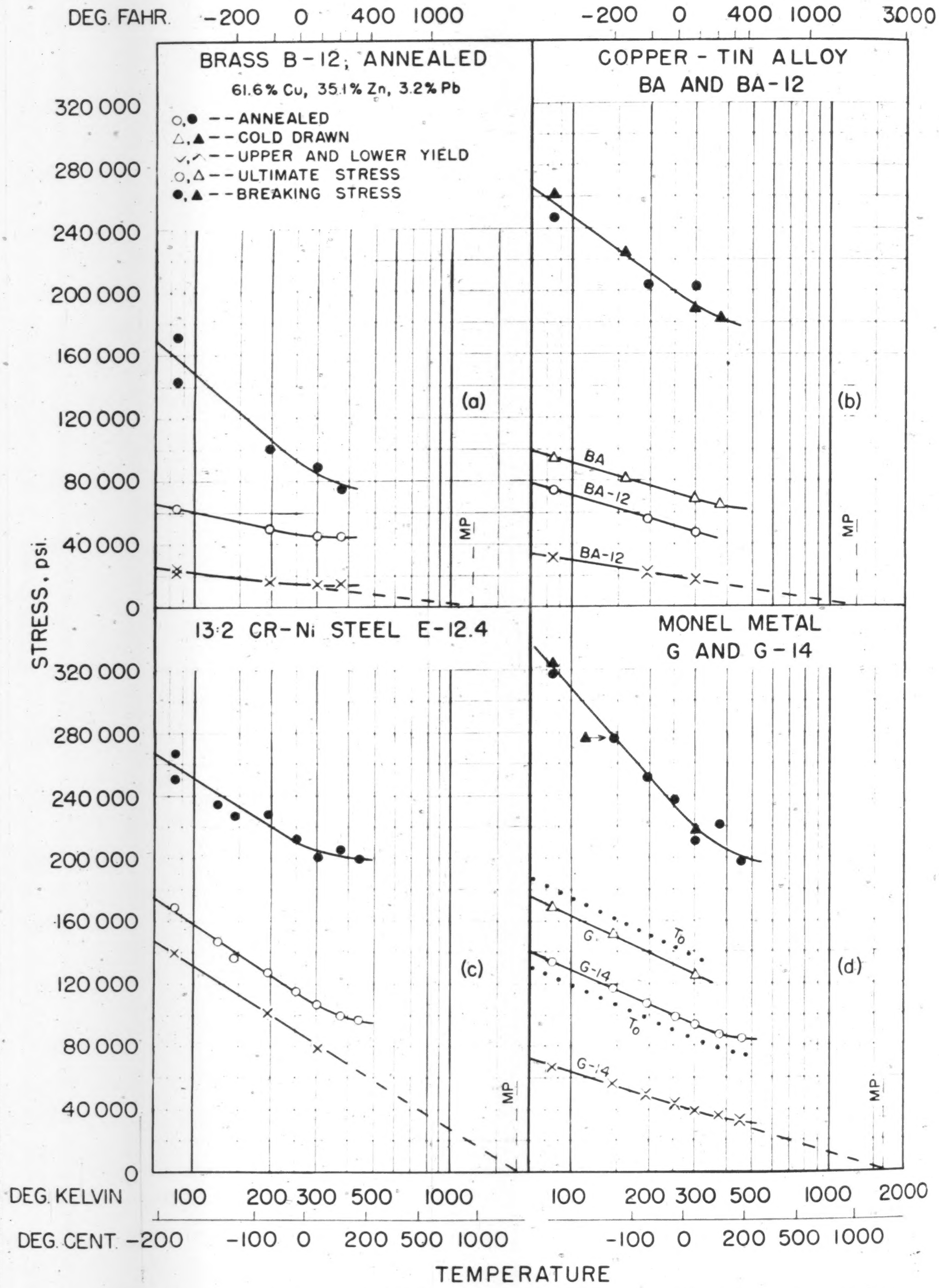

Fig. 14.—Variation of the Strength of Three Non-ferrous Metals and 13:2 Chromium-Nickel Steel with Temperature.

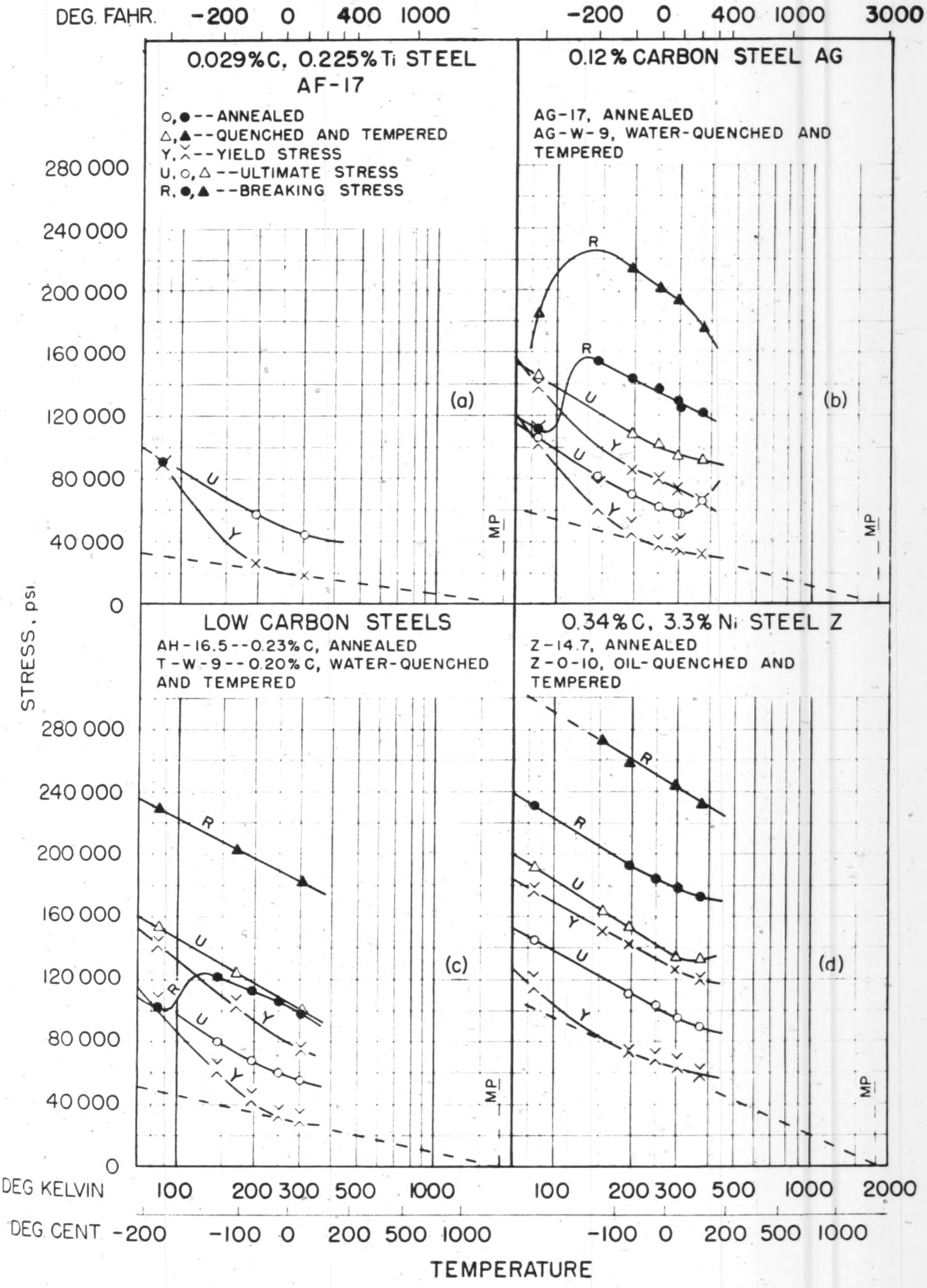

Fig. 15.—Effect of Heat Treatment and Composition on the Variation of the Strength of Steels with Temperature.

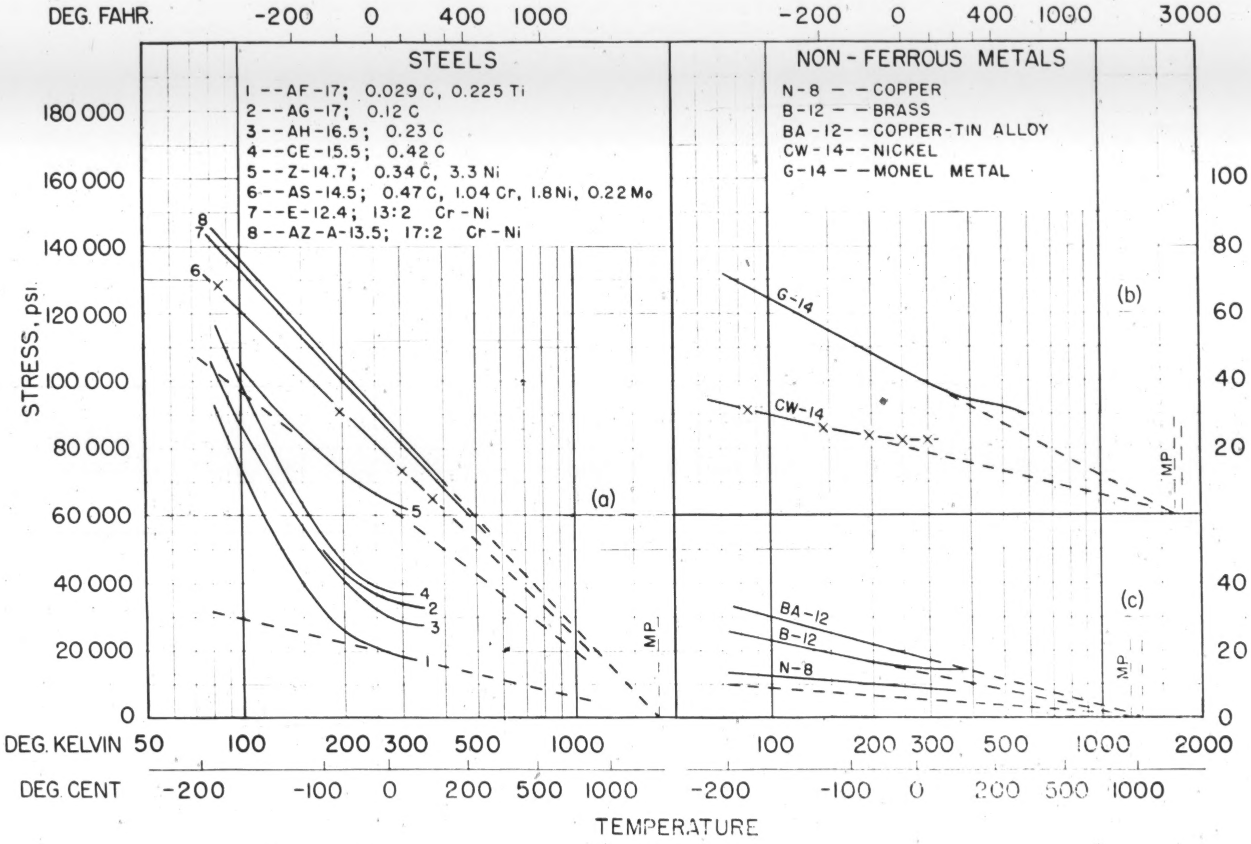

FIG. 16.—Variation of the Yield Stress of Annealed Metals with Temperature.

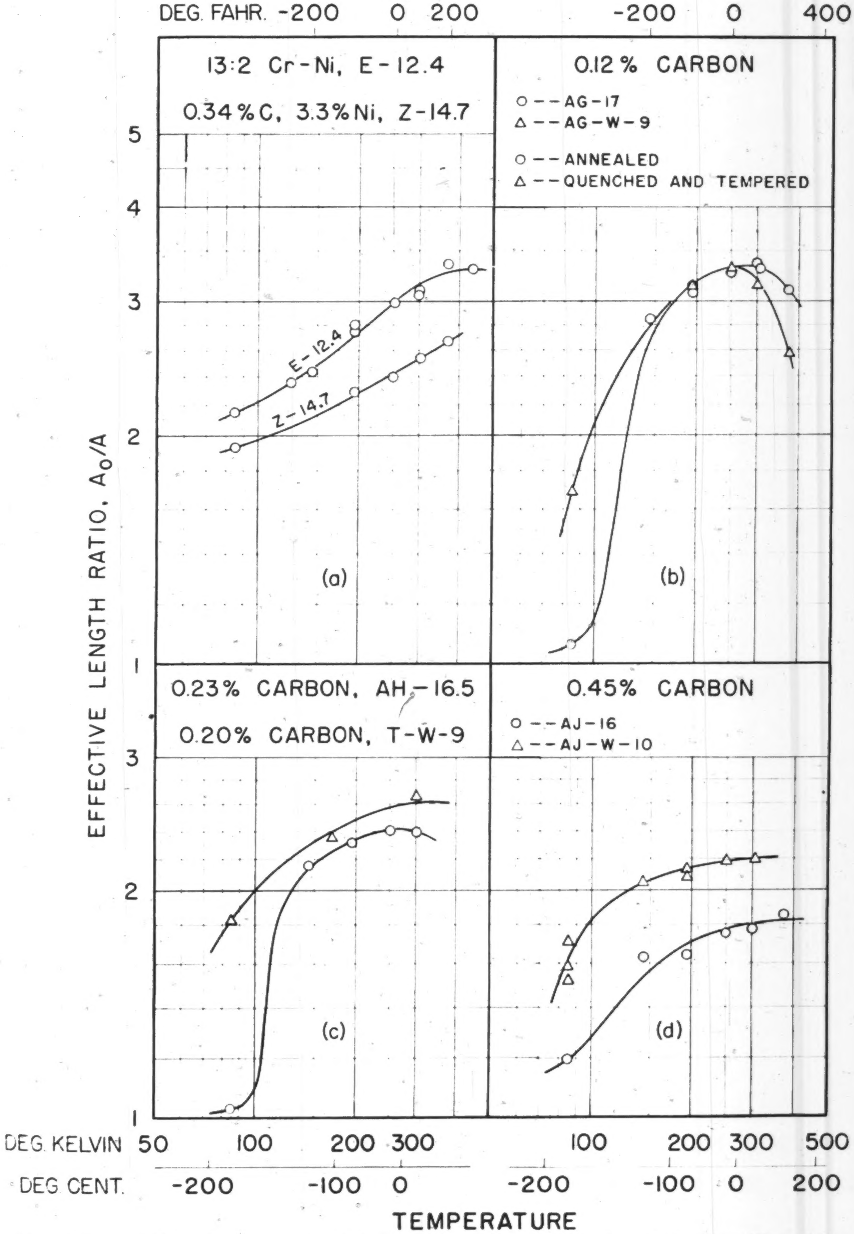

Fig. 17.—Effect of Heat Treatment and Composition on the Variation of the Ductility of Steel with Temperature.

DISCUSSION

Mr. P. G. Jones[1] (*by letter*).—The authors' results on the influence of combined stresses, stress concentration, and temperature on the mechanical properties of steels are very interesting. Of particular interest to the writer is the authors' statement that "the evidence indicates that increase of the strain rate to nearly a million times the rate for an ordinary tension test generally causes no decrease of the ductility of either ferrous or non-ferrous metals, provided that the tests are made with unnotched specimens." It is assumed that the authors are referring to tests made at room temperature and for this reason it is felt that a further discussion of the effect of rate of strain at temperatures lower than room temperature may be desirable.

An investigation is being conducted at the University of Illinois to determine the effect of the embrittling factors of stress concentration, state of stress, temperature, and rate of strain on the ductility of killed and rimmed steels. Preliminary results are in agreement with the authors' statement for tests on unnotched tension specimens made at room temperature and at rates of strain varying from 10^{-6} to about 2×10^3 per second. However, for temperatures lower than room temperature, unnotched specimens which show high ductility under static loads may be made to fail in a completely brittle manner by increasing the rate of strain to a sufficiently high value which depends on the temperature of the test. This seems to lend support to the prevalent view that any metal will become brittle if the strain rate is sufficiently high. The strain rates which produce brittle fractures at room temperature for the metals tested are apparently above 2×10^3 per second. For temperatures lower than room temperature (-20 F. say) the rate of strain necessary to produce brittle fracture falls below 2×10^3 per second.

Although there are considerable data which indicate little change in ductility of metals as measured by percentage elongation and reduction of area for strain rates at room temperature in the impact range (above 10 per second) there is evidence, [2, 3] that an increase in strain rate will cause an appreciable decrease in ductility for strain rates in the range of commercial testing (10^{-4} to 10^{-1} per second). Also the data of Manjoine referred to by the authors and data reported by Fehr, Parker and DeMicheal,[4] and others indicate an appreciable increase in ductility when the strain rates are increased from so-called static rates to the lower end of the impact range. Also data reported by Quinney,[5] and others show that when the rate of strain is lowered to the so-called "creep range" (below 10^{-6} per second) there is a considerable reduction in the ductility from that found in ordinary static tests.

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[1] Assistant Professor in Theoretical and Applied Mechanics, University of Illinois, Urbana, Illinois.

[2] R. L. Kenyon, "Per Cent Elongation in the Tensile Test as a Method of Measuring the Ductility of Thin Sheets," *Metals and Alloys*, Vol. 3, p. 220 (1932).

[3] P. G. Jones and H. F. Moore, "An Investigation of the Effect of Rate of Strain on the Results of Tension Tests of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 610 (1940).

[4] R. O. Fehr, E. R. Parker, and D. J. DeMicheal, "Measurement of Dynamic Stress and Strain in Tensile Test Specimens," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 66, pp. A65–A71 (1944).

[5] H. Quinney, "Time Effect in Testing Metals," *The Engineer*, Vol. 157, pp. 332–334 (1934).

The data reported by the authors add materially to the study of the influence of embrittling factors on the behavior of metals. There is need, however, for a further investigation of the effect of rate of strain on the ductility of unnotched specimens subjected to low temperatures.

MESSRS. D. J. MCADAM, JR., G. W. GEIL, AND R. W. MEBS (*authors' closure by letter*).—Our mention of the fact that the ductility of an unnotched specimen of ferritic steel is not decreased by an increase in the strain rate to a high value at room temperature was not intended to imply that the strain rate would have a similar effect at low temperatures. We wished to emphasize the fact that an increase in the strain rate at room temperature to a very high value does not decrease the ductility of an unnotched specimen, but does decrease the ductility of a notched specimen. This evidence combined with the evidence in Figs. 2, 4, 6, and 12 of the paper suggest that an important factor in the cold brittleness of ferritic steels is their lack of ability to relieve stress concentration at low temperatures or at high strain rates. With decrease in temperature or increase in the strain rate, unrelieved stress concentration becomes apparent in notched specimens of ferritic steels, but not in face-centered cubic metals in the same condition. This effect of low temperature is not due primarily to the decrease in ductility. A ductility that is sufficient to relieve stress concentration in a face-centered cubic metal at low temperatures or in a ferritic steel at room temperature is not sufficient to relieve stress concentration in a ferritic steel at low temperatures.

This peculiarity of ferritic steels is illustrated in the accompanying Fig. 1. In this figure, comparison is made between annealed 0.42 per cent carbon steel CE-15.5 (Fig. 12(*c*)) and heat-treated K-monel metal CK-10.6 (**12**). At room temperature, the effects of notches on the ductility of these two metals are about the same, and neither of the metals shows any evidence of unrelieved stress concentration, even when the notch angle is 50 deg. or less (Fig. 12). With decrease in temperature, however, the two metals behave very differently. The K-monel metal retains its ductility and its ability to relieve stress concentration. The ferritic steel, however, becomes less ductile, and becomes less able to relieve stress concentration even when the ductility would be ample for relief of stress concentration at room temperature. Within the field bounded by curve *W* in the accompanying Fig. 1(*a*), stress concentration is not completely relieved, and the amount of unrelieved stress concentration increases with departure from the boundary.[6]

The course of curve *W* as it extends to the right is the resultant of two variables: increase in the ability to relieve stress concentration (because of increase in temperature), and increase in the initial stress concentration with decrease in the notch angle. In the rise of curve *W*, the rapid increase in initial stress concentration with decrease in the notch angle is the dominant factor. In the descent of the curve, the dominant factor is the effect of increasing temperature on the ability to relieve stress concentration. Between about −130 C. and room temperature the ductility required for complete relief of stress concentration decreases rapidly, and the metal becomes able to relieve increasingly high stress concentration.

The alloying elements in the ferritic steel represented in the accompanying

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[6] The boundary of this field is determined approximately by a study of Figs. 5, 6, and 12.

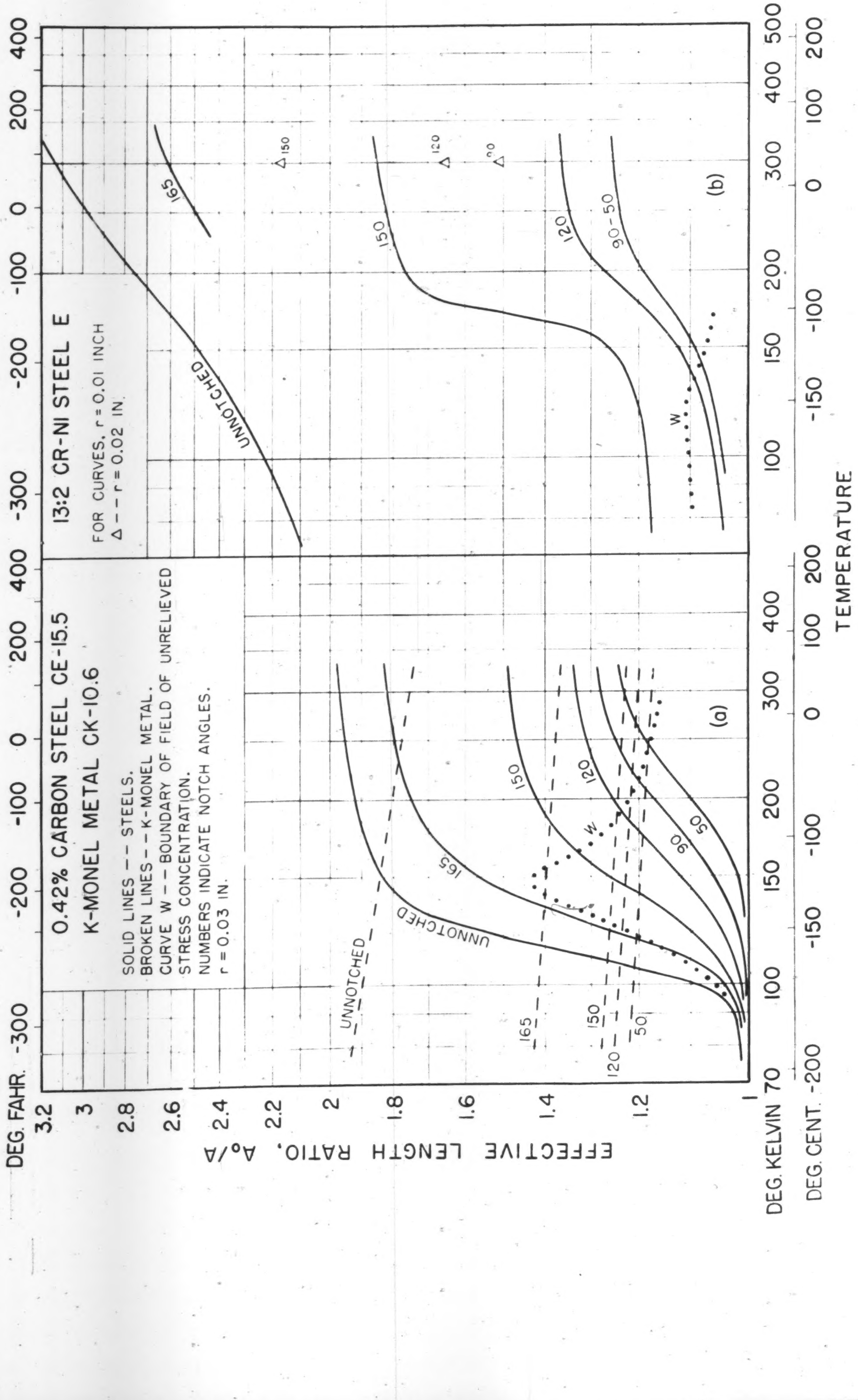
0.42% CARBON STEEL CE-15.5
K-MONEL METAL CK-10.6
SOLID LINES -- STEELS.
BROKEN LINES -- K-MONEL METAL.
CURVE W -- BOUNDARY OF FIELD OF UNRELIEVED STRESS CONCENTRATION.
NUMBERS INDICATE NOTCH ANGLES.
r = 0.03 IN.
13:2 CR-NI STEEL E
FOR CURVES, r = 0.01 INCH
Δ -- r = 0.02 IN.
UNNOTCHED
165
150
120
90
50
90-50
W
(a)
(b)
DEG. FAHR.
-300
-200
-100
0
200
400
EFFECTIVE LENGTH RATIO, A₀/A
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
DEG. KELVIN
70
100
150
200
300
400
500
DEG. CENT.
-200
-150
-100
0
100
200
TEMPERATURE

Fig. 1.

Fig. 1(*b*) have greatly diminished the adverse effect of low temperature on ductility (Fig. 17(*a*)) and have also greatly diminished the effect of low temperatures on relief of stress concentration. Although decrease in temperature had a great effect on the ductility of the notched specimens, the only specimens that gave evidence of incompletely relieved stress concentration were those tested at −188 C. and with notch angle less than 150 deg. Moreover, the root radius of the notches used in obtaining the curves in Fig. 1(*b*) was only 0.01 in., whereas the curves in Fig. 1(*a*) were obtained with root radius 0.03 in. The initial stress concentrations for corresponding notch angles, therefore, were much greater in the 13 per cent chromium, 2 per cent nickel steel than in either the 0.42 per cent carbon steel or the K-monel metal. As indicated approximately by curve *W* in Fig. 1(*a*), the field of unrelieved stress concentration is confined within a range of very low temperatures and small ductilities **(7)**.

The evidence mentioned by Mr. Jones would not seem to be sufficient to warrant his support of the prevalent view that any metal will be brittle if the strain rate is sufficiently high. In impact tests of notched specimens at −188 C., face-centered cubic metals give higher values than at room temperature. Moreover, these metals are about as ductile in static tests in liquid hydrogen −252.7 C. as at room temperature. The equivalent strain rate corresponding to a static tension test in liquid hydrogen is millions of times the rate corresponding to a test in liquid air. Some metals, therefore, are not embrittled by any strain rates that may be applied in service or in an engineering test.

STRUCTURAL CHANGES IN CARBON AND MOLYBDENUM STEELS DURING PROLONGED HEATING AT 900 TO 1100 F., AS AFFECTED BY DEOXIDATION PRACTICE

By G. V. Smith,[1] R. F. Miller,[2] and C. O. Tarr[2]

Synopsis

Annealed and normalized samples of steels—three with 0.1 per cent carbon, and six with 0.1 to 0.2 per cent carbon and 0.5 per cent molybdenum—of different deoxidation practice were tested at 900, 1000, and 1100 F. for periods up to 5000 hr., and then subjected to hardness tests and to metallographic examination for microstructural changes.

Introduction and Summary

Engineering structures used for prolonged service at elevated temperature are generally designed on the basis of creep or stress-rupture data, which are generally obtained in tests of short duration relative to the service life. These properties depend on the microstructure of the metal, and inasmuch as metals undergo changes in microstructure when held at elevated temperature, the creep and stress-rupture strengths in reality vary continuously, generally decreasing, throughout the service life. It is therefore desirable to study the microstructural changes occurring over longer periods at the temperature of interest, or as simulated, though not always equivalently, by shorter tests at higher temperature. Accordingly, a number of samples, comprised of three carbon (0.1 per cent) steels of similar composition but deoxidized differently, and six molybdenum steels (0.1 to 0.2 per cent carbon, 0.5 per cent molybdenum) similar except for silicon content and mode of deoxidation, were tempered* for periods ranging up to 5000 hr. at 900, 1000, or 1100 F.; and observations were made of (*a*) hardness (measured at ordinary temperature), and (*b*) microstructure particularly with respect to the progress of spheroidization and the possible appearance of graphite. All but one steel were of commercial manufacture, as commonly used for elevated temperature service, and each was employed in two initial conditions, annealed (A) and normalized (N).

The main results and inferences from them follow:

The hardness of most of the carbon steel samples first increased slightly with time at temperature, then decreased slowly at about the same rate at each of the three temperatures; the changes appeared to be uninfluenced by the deoxidation practices used. The increase was greatest in the annealed samples held at 1000 F. The hardness of the annealed molybdenum steels followed the general pattern of the carbon steels, but the normalized samples behaved in a way characteristic of precipitation-hardening systems—that is, the hardness increased initially, more slowly but to a higher value the lower the temperature, and then decreased (Table II and Fig. 1). This phenomenon combined with the simultaneous spheroidization and agglomeration of the carbide makes the picture of the hardness change less simple than for the carbon steels and annealed molybdenum steels.

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[2] Now with Carnegie-Illinois Steel Corp., Pittsburgh and McKeesport, Pa., respectively.

* The use of the term "tempering" to apply to the holding of annealed as well as normalized steel samples at subcritical temperatures may not be conventional, but is used throughout this paper for the sake of convenience.

The rate of spheroidization (Table III and Fig. 9) of the normalized was generally greater than for the annealed steels, as is to be expected from the finer initial structure, but the effect was less marked in the carbon steels. In the normalized carbon steels this rate was highest in the high titanium-treated steel. In the molybdenum steels the rate increased with increasing silicon plus aluminum addition, whereas a large aluminum addition without silicon was associated with a lower rate which, however, is probably to be attributed to a coarser initial microstructure.

Graphite formed in all the carbon steels, and at about the same rate in both normalized and annealed specimens (Table III and Fig. 9). In the six molybdenum steels, it formed only in the three to which aluminum had been added; in these three the rate seemed to be faster the higher the silicon content, and faster in the annealed than in the normalized samples, only one of which showed graphite. In both groups graphitization was generally faster the higher the temperature within the range studied.

It has become apparent that a great deal of further work is needed, particularly on the nature of carbides—how it depends on the presence of alloying elements, whether added as such or as deoxidizers, and how the carbides are modified by temperature and time. Obviously therefore many of the outstanding questions cannot be answered in the immediate future.

ORIGIN OF PROBLEM

Steels for elevated temperature service are nearly always applied in an annealed or normalized condition, their microstructure then consisting of proeutectoid ferrite and an aggregate of ferrite and carbide. When held at sufficiently elevated temperatures, yet below that at which austenite begins to form, the structure changes, principally in the direction of a spheroidization of the carbide which, having been present initially in a lamellar or plate-like form, tends to assume a globular form. In alloy steels it is to be expected that changes in composition and nature of the carbide may occur concurrently with this spheroidization. Another change frequently encountered after a steel has been at elevated temperature for a long time, is a reversion of carbide to the more stable form graphite. Both these changes occur progressively with time and seemingly independently of one another, the only common factor perhaps being the rate of diffusion. In an attempt to get more information on these changes, and how they are affected by the composition and mode of deoxidation of the steel, a survey of the literature was made before experimental work was undertaken.

SURVEY OF LITERATURE

What is called carbide or cementite or Fe_3C probably does not always correspond exactly to the formula Fe_3C even in pure iron-carbon alloys, and certainly does not when other elements are present. Bain, Davenport, and Waring (**1**)[3] have shown, for example, that manganese in steel is capable of forming a carbide approximating Mn_3C in composition, and that this carbide forms a continuous series of solid solutions with Fe_3C. Accordingly, since all commercial steels contain manganese, it would seem that the carbide in such steels must contain both iron and manganese. On the other hand, when one or more elements which form a very stable (relatively insoluble, or high melting) carbide, is present, an entirely different type of carbide may form, dependent upon the particular element or elements added and the prior treatment. It appears, however, that for small amounts of the added element, it enters into the ordinary iron-carbide lattice until a certain maximum has been exceeded, whereupon a new type of carbide appears; moreover, the new carbide may dissolve iron to some extent. In extreme instances this mutual solubility of iron carbide and added elements, or of alloy carbides and iron, may be very slight.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, p. 502.

It is only recently that the general considerations outlined above have received the attention they deserve. Bowman, Parke, and Herzig (2) have reported preliminary results of an investigation of the partition of molybdenum between carbide and matrix in steels. Mehl, in discussing this paper, pointed out that the initial distribution need not be that at equilibrium, nor need the equilibrium distribution at one temperature be the same as at another temperature. Crafts and Offenhauer (3, 4) recently determined by X-ray diffraction the types of carbide existing in low chromium-molybdenum steels which had been quenched and tempered, finding that on tempering at temperatures below about 930 to 1020 F. the carbide type was Fe_3C, but at higher tempering temperatures was of an alloy type. It may be that the Fe_3C type persists at the lower temperatures only because of insufficient mobility of the chromium or molybdenum atoms, the carbon then combining with the more abundant iron, and therefore that the apparent inversion temperature of the carbide may not be real. A definitive test suggests itself, namely, to form the alloy carbide at higher temperature and determine whether it transforms slowly to the simple carbide type at lower temperature. In any event, it is probable that equilibrium with respect to the nature and composition of the carbide phase is not attained in ordinary heat-treatment operations, because such treatments do not last long enough to permit the necessary diffusion. However, it should be apparent that the equilibrium relationships are of prime importance when a ferrous alloy is being used in elevated temperature service, for changes in equilibrium may then be expected to occur. Accordingly, the design engineer needs information concerning the mechanical properties of metals after these changes have occurred; this is particularly true when it is considered that the spheroidization which generally accompanies these changes tends to lower the strength. European investigators have been active in correlating creep resistance of steels with equilibrium phase diagrams (5, 6).

With respect to the other main type of microstructural change, the formation of graphite, little is known about it in low-carbon steels, especially when alloying elements are present. It appears, however, that Fe_3C is not a stable phase in iron-carbon alloys, at least at temperatures below about 2050 F. (7). Graphitization has not until recently been a problem to users of steel at elevated temperature because it occurs relatively slowly and causes only a slight loss of strength. Recently, however, instances have been reported in which slow graphitization has occurred in a localized, and therefore dangerous[4], network-like distribution adjacent to welds in molybdenum steel pipe after some years of service. In this connection, Smith, Miller, and Tarr (**9**) pointed out that the stability of a carbide with respect to graphitization must be dependent upon its chemical composition, and demonstrated that graphite formed in molybdenum steel during service at relatively low temperature could be caused to revert to carbide at a higher but yet subcritical temperature. Austin and co-workers (**10, 11**) have begun to study graphitization as affected by alloying elements, but a great deal is yet to be done, particularly with respect to the nature of the carbide and the distribution of added elements between carbide and metal phases.

Investigation of structural changes occurring during tempering at elevated temperature has not been particularly intensive except in steels having initially a martensitic structure. Engel (**12**) studied the softening rates of a 0.94 per cent carbon steel when tempered from different initial structures, and found that the smaller the initial carbide particle size, the faster the rate of softening; this is largely the result of steeper average concentration gradients and the consequent faster diffusion and greater solubility of the finer particles. Bain (**13**) has devoted much attention to the tempering reactions of quenched steels, as have Austin and co-workers (**10, 11, 14, 15**) who also provide an extensive review of this literature (**14**). Unfortunately, however, steels subjected to service conditions involving creep at elevated temperature are not generally used in the quenched condition, because of poorer creep strength.

Some investigators have recorded observations of microstructural changes encountered during creep or stress-rupture test at elevated temperature. Jenkins, Mellor, and Jenkinson (**16**) reported on a study of the changes in carbon steels of 0.17 to 1.14 per cent carbon during stress-rupture test at elevated temperature, in which it was found that deformation accelerated spheroidization and graphitization, and that graphite precipitated the more readily the higher the carbon content, though this behavior was dependent in some part on deoxidation practice. White, Clark, and Wilson (**17**) noted progressive spheroidization in S.A.E. 1015 steel of coarse-grain deoxidation practice during creep tests at 1000 F., and Miller and co-workers (**18, 19**) reported microstructural changes in a wide variety of steels when held at elevated temperature. Weaver (**20**) studied the effect of carbide spheroidization upon the creep strength of molybdenum steel.

Altogether, therefore, the information available on the changes which may occur in steels during prolonged service at elevated temperature leaves much to be desired. Accordingly we decided to examine the changes in a number of steels such as have commonly been used at high temperature (as in recent large power stations) when held at a temperature of 900, 1000, and 1100 F. respectively, for a period extending up to 5000 hr. (7 months). It might be remarked that in the molybdenum steels studied there is a relatively high ratio of percentage of alloying element to percentage of carbon, as compared to alloys most commonly studied (**10, 11**), and therefore the possibility of occurrence of greater amounts of alloy carbides which may appreciably affect the processes of spheroidization and graphitization.

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[4] Localized graphitization is dangerous because, owing to differences in solubility and stability, carbon atoms migrate from the remainder of the sample to the graphite, much as a blotter sops ink. See reference 8 for a brief description and a possible explanation of the phenomenon.

MATERIALS AND HEAT TREATMENT

Three bars of S.A.E. 1015 steel from three heats of similar composition but differing deoxidation practice, and six bars of 0.5 per cent molybdenum steel from four heats of similar composition but varying deoxidation practice, were selected for examination. The composition and deoxidation practice of each is given in Table I. The first four molybdenum steels are from two heats with low and high ferro-silicon additions in the ladle, in each case with and without aluminum additions in the mold. The fifth is of similar composition but had been deoxidized with ferro-silicon-zirconium in the ladle and had no addition in the mold. The sixth had no ladle addition but a very high aluminum addition in the mold; it was very "dirty" but was included because of the high aluminum addition. The three carbon steels are of very similar composition but were deoxidized in the ladle with 10 lb. ferro-silicon per ton of steel and differing amounts of ferro-carbon-titanium, and in the mold by differing amounts of aluminum. It should be remarked that these carbon steels are not typical of that used for carbon-steel pipe; titanium deoxidation represents a practice introduced during a period of severe aluminum shortage in the early part of the war.

TABLE I.—ANALYSIS AND DEOXIDATION PRACTICE OF MATERIALS.

Steel	Analysis, per cent												Deoxidizers Added[a]		After Carburizing Test	
	C	Mn	P	S	Si	Cu	Cr	Mo	Ti	Zr	Al	Al_2O_3	Ladle, lb. per ton	Mold, lb. Al per ton	ASTM Grain Size	Structural Normality
							MOLYBDENUM STEEL									
No. 1	0.16	0.82	0.020	0.027	0.47	0.02	0.03	0.48	....	....	0.039	0.009	0.9 FeMn 12.6 FeSi	1.0	6–8	Moderately abnormal
No. 2	0.16	0.84	0.019	0.030	0.47	0.03	0.03	0.47	....	....	0.006	0.003	0.9 FeMn 12.6 FeSi	0.0	2–4	Slightly abnormal
No. 3	0.20	0.84	0.026	0.026	0.22	0.02	0.02	0.48	....	....	0.005	0.006	0.9 FeMn 7.7 FeSi	0.0	2–3	Slightly abnormal
No. 4	0.21	0.85	0.024	0.026	0.23	0.03	0.01	0.48	....	....	0.035	0.005	0.9 FeMn 7.7 FeSi	1.5	6–8	Moderately abnormal
No. 5	0.20	0.73	0.031	0.031	0.23	0.04	0.24	0.51	....	0.04	0.004	0.004	5.1 FeSiZr	0.0	2–4	Normal
No. 6	0.11	0.46	0.009	0.012	0.02	...	0.17	0.43	....	....	0.084	0.009	0.0 FeSi	3.0	7–8	Moderately abnormal
							CARBON STEEL									
No. 7	0.13	0.45	0.011	0.023	0.19	....	....	....	0.001	....	0.007	0.003	10.0 FeSi 0.0 FeCTi	1.0	2–4	Slightly abnormal
No. 8	0.14	0.47	0.008	0.022	0.21	....	....	....	0.003	....	0.004	0.002	10.0 FeSi 4.0 FeCTi	0.5	1–4	Slightly abnormal
No. 9	0.14	0.46	0.009	0.028	0.19	....	....	....	0.002	....	0.005	0.002	10.0 FeSi 6.0 FeCTi	0.0	3–4	Slightly abnormal

NOTE.—Ni and V were nil in steels 1–5 and not determined in the remainder.

[a] The manganese content of the ferro-manganese was in all cases 80 per cent.
The silicon content of the ferro-silicon was 80 per cent for steels nos. 1 and 2, and 50 per cent for steels nos. 3 and 4.
The ferro-silicon-zirconium had 52 per cent silicon and 39 per cent zirconium.
The analysis of the deoxidizers used for the remaining steels is not known.

Initial Heat Treatment:

It was considered desirable to simulate commercial practice in the structures to be used in the tempering studies. Since commercial practice usually involves air-cooling (normalizing) or furnace-cooling (annealing) from the austenitizing temperature, each steel was treated in both manners. An austenitizing temperature of 1650 F. for the molybdenum steels and 1600 F. for the carbon steels was used; specimens were held at temperature $\frac{1}{2}$ hr. before cooling. The molybdenum steels were treated in the form of small bars approximately $\frac{1}{2}$ by $1\frac{1}{2}$ in. in cross-section, and the S.A.E. 1015 steels as 1-in. rounds. Air-cooling was accomplished by removing the bars (4 to 6 in. in length) from the furnace and setting them on end on refractory brick; the end in contact with the brick was discarded.

Tempering:

In most elevated temperature service, such steels are under 1100 F. and, in fact, mostly below 1000 F.; with this in mind, tempering temperatures of 900, 1000, and 1100 F. were chosen. Tempering periods were 5, 15, 50, 100, 300, 500, 1000, 3000, and 5000 hr., a separate specimen being used for each period. Tempering was conducted in coke-covered lead pots, periodically deoxidized by immersing an oil-soaked briquet into the lead. Temperature fluctuation was ±5 F. up to 1000 hr. and ±20 F.

TABLE II.—TABULATION OF VICKERS PYRAMID HARDNESS NUMBERS AS DETERMINED ON ALL STEELS
Each hardness value represents the average of four indentations.

Steel	Deoxidizers Added		Temperature of Tempering deg. Fahr.	Air Cooled and Tempered					Furnace-Cooled and Tempered				
	Ladle, lb. per ton	Mold, lb.Al per ton		No. of Hours at Temperature					No. of Hours at Temperature				
				0	5	100	1000	5000	0	5	100	1000	5000
MOLYBDENUM STEEL													
No. 1	12.6 FeSi 0.9 FeMn	1.0	900	184	178	173	188	186	138	142	144	140	145
			1000		189	173	184	166		145	143	147	144
			1100		177	176	161	148		148	144	139	136
No. 2	12.6 FeSi 0.9 FeMn	0.0	900	196	190	190	203	204	137	140	140	135	140
			1000		197	194	193	170		145	142	142	148
			1100		183	172	171	154		150	144	136	137
No. 3	7.7 FeSi 0.9 FeMn	0.0	900	203	198	196	209	208	135	146	141	135	131
			1000		203	201	201	171		144	144	135	134
			1100		198	186	171	158		146	137	135	128
No. 4	7.7 FeSi 0.9 FeMn	1.5	900	193	198	191	193	192	134	141	143	136	139
			1000		188	192	187	166		146	143	140	140
			1100		183	172	166	151		144	142	143	130
No. 5	5.1 FeSiZr	0.0	900	211	206	205	215	221	132	143	140	136	135
			1000		211	212	206	189		144	141	140	146
			1100		202	197	182	165		148	144	145	135
No. 6	0.0 FeSi	3.0	900	120	122	124	122	124	108	125	121	115	112
			1000		116	114	126	121		...	...	117	121
			1100		126	126	131	121		121	122	120	116
CARBON STEEL													
No. 7	10.0 FeSi 0.0 FeCTi	1.0	900	113	116	114	108	106	98	104	104	102	99
			1000		110	106	104	101		116	117	102	98
			1100		...	...	105	101		...	106	99	93
No. 8	10.0 FeSi 4.0 FeCTi	0.5	900	119	114	114	105	106	103	106	109	107	100
			1000		113	111	106	105		118	...	102	100
			1100		120	106	105	98		116	104	105	98
No. 9	10.0 FeSi 6.0 FeCTi	0.0	900	118	126	115	112	106	102	109	106	107	101
			1000		117	115	111	102		122	118	102	100
			1100		...	106	106	97		114	106	106	93

for the 3000- and 5000-hr. periods. The samples were treated as approximately $\frac{3}{8}$-in. thick half-slices, were sectioned after tempering, and examined on the freshly exposed surface.

HARDNESS MEASUREMENTS

Vickers hardness (20-kg. load) was measured in investigating the results of tempering; Table II is a tabulation of all values measured. Not all specimens were examined in this way, but in general only those needed to determine temperature-time-hardness trends. The results for one of the molybdenum steels, No. 2, and for one of the carbon steels, No. 8, are shown in Fig. 1 to illustrate the general type of behavior. The semi-log plot was chosen for convenience and because many solid-state reactions proceed in such a fashion that the semi-log plot is linear. Departure from a straight line, moreover, may be taken as an indication of the occurrence of effects other than simple spheroidization; Austin, *et al.* (**10, 11**), for example, noted departure at the onset of graphitization.

Carbon Steels:

The several steels show a similar variation in hardness with time at temperature, that is, hardness decreases with increasing time beyond 5 hr., and in an approximate, though not exact, linear manner on the semi-logarithmic scale. Graphitization, detected metallographically in the specimens tempered for the longer periods, evidently had not progressed sufficiently to affect the hardness. A curious fact is the seeming independence of the rate with respect to temperature and the small differences in hardness developed at the different temperatures. Another curious observation, in a few of the normalized and in all the annealed specimens, is the

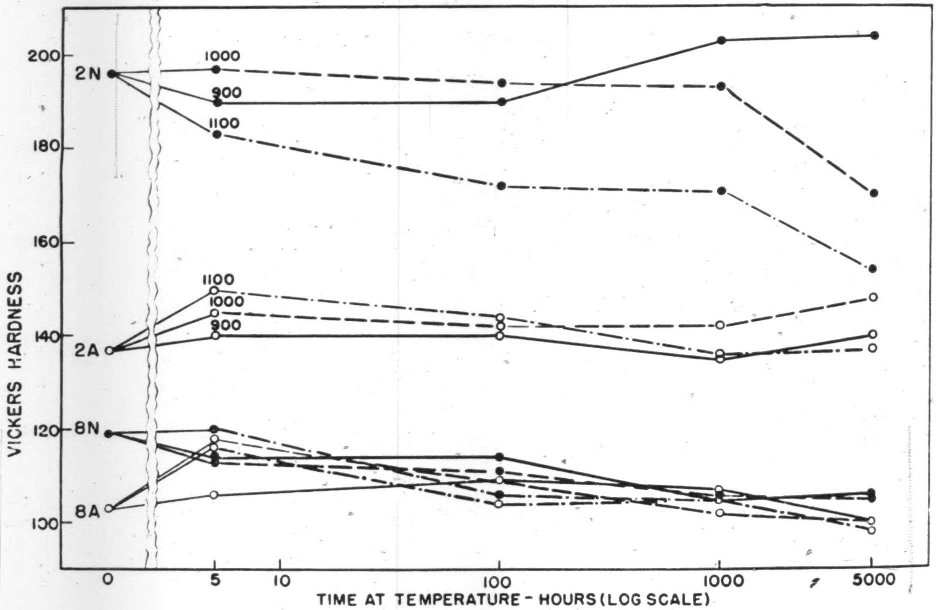

FIG. 1.—Influence of Time at 900, 1000, and 1100 F. on the Hardness of a Carbon Steel (No. 8) and a Molybdenum Steel (No. 2) in the Normalized (*N*) and Annealed (*A*) Conditions.

increase in hardness over that of the original caused by the 5-hr. tempering; this is particularly evident in the annealed steels in which some increase is retained up to 1000 hr. at temperature. This indicates that some process other than simple spheroidization is occurring. The effect, perhaps a precipitation hardening, appears to be greatest at 900 F. in the normalized samples and at 1000 F. in the annealed samples, and is great enough to cause the hardness of the annealed samples, which initially was some 15 points softer, to increase to a level comparable with that of the normalized series. The effect of larger aluminum addition with simultaneously smaller titanium addition is not large enough or clear enough to warrant discussion. In these steels titanium probably should not be considered as an alloying element in the ferrite since any titanium in excess of that required for deoxidation would combine with carbon (or nitrogen) and remain inert owing to insufficiently high temperature of treatment.

Molybdenum Steels:

In molybdenum steel, something other than simple spheroidization occurs at elevated temperature, as is apparent in Fig. 1, but for this there is a ready explanation. On tempering such steels a fine groundmass precipitate develops (see below), appearing earlier the higher the temperature, and coarsening with time at constant temperature, both in the manner of a typical precipitation-hardening system. Correspondingly, the change is reflected in the hardness. Owing to this precipitation, it becomes difficult to separate the effect of precipitation from that of spheroidization and agglomeration.

The differences among the steels were more prominent in the normalized than in the annealed condition. The initial hardness values were nearly identical (Table II) for the annealed condition with the exception of the very high aluminum steel, No. 6; the normalized samples showed a greater spread.

With minor exceptions the hardness change on tempering the normalized steels is similar in all except No. 6. At 900 F., hardness rises after the 100-hr. period and at 5000 hr. has not yet fallen appreciably. At 1000 F., the effect has shifted to shorter time and become considerably smaller or even undetectable; an exception is No. 1 whose hardness rises between 100 and 1000 hr. At 1100 F., the effect is not evident except that the softening curves do not show the linear variation sometimes observed (**10,11**). This "secondary hardening"[5] was least pronounced in steels Nos. 4 and 6, deoxidized with 1.5 and 3.0 lb. of aluminum per ton; the significance of this is not known.

As noted earlier, the effects of agglomeration and of precipitation cannot be distinguished. Evidently the hardness as determined represents some sort of average of the hardening due to the groundmass precipitate and the softening which accompanies spheroidization and agglomeration of the carbide and of the precipitate. At the lower temperature, hardening predominates; at the higher, softening predominates.

The annealed samples all show much less evidence of either softening or hardening than the normalized. The reason for this may be that equilibrium is more nearly attained during the slower cooling, while the lesser softening may be attributed to the coarser carbide which likewise results from slower cooling. It may also be noted that, as in the annealed carbon steels, short tempering of the annealed samples increases hardness. Evidently there is need for more fundamental study of the tempering process in low-carbon steels with initial structures other than martensite.

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[5] The term "secondary hardening" is generally reserved for a reversal in the softening during tempering of quenched and hardened steels, but is used here because the two processes are certainly akin.

With respect to the effect of aluminum on the retention of hardness, comparison for steels Nos. 3 and 4 and for steels Nos. 1 and 2, at the "low" and "high" silicon levels, respectively, shows in both that aluminum addition lowers the hardness of normalized material, and this difference is preserved during tempering. The very large addition, 3 lb. per ton, of aluminum to steel No. 6 bears out this trend; the loss of hardness is indeed surprising, though the low carbon and manganese content, in comparison with the other steels, is probably an important factor in bringing this about. For the annealed steels, excepting steel No. 6, the initial differences in hardness are inappreciable, and no great differences appear during tempering.

The effect of varying silicon cannot be evaluated owing to other differences in composition. For example, of the three (Nos. 2, 3, and 5) to which no aluminum addition had been made, steel No. 5 with the lowest silicon addition had the greatest hardness in the normalized condition and best retained hardness on tempering at each temperature; but the silicon was added as Fe-Si-Zr and there was an appreciable chromium content. Of the two steels with higher silicon addition, No. 3 with 7.7 lb. was slightly superior to No. 2 with 12.6 lb., but the difference may be due to the different carbon content. The behavior of the annealed samples is not in conformity with the relationship noted for the normalized samples, though the spread is of a minor nature and probably not significant.

Although graphite was observed in some samples, as discussed in the following section on metallographic studies, it did not, in our opinion, develop sufficiently to affect the hardness.

STUDIES OF MICROSTRUCTURE

Initial Structures:

Since changes with time at elevated temperature are dependent upon the initial state, it is of interest to examine the structure in the two initial conditions, normalized and annealed, and to determine whether the variation in deoxidation practice resulted in noticeable differences. The greatest difference, of course, is between the annealed and the normalized states. This difference, which is not great for carbon steels, is illustrated in Figs. 2 and 3 for normalized and annealed steel No. 9, respectively; in the former condition, as would be expected, the pearlite lamellae have a slightly finer spacing and the pearlite areas are somewhat smaller than in the annealed condition. Steels Nos. 7 and 8 are very similar to No. 9, and the effect of deoxidation practice within the limits studied is apparently inappreciable.

The molybdenum steels were more noticeably affected by variation in deoxidation practice, particularly in the normalized condition. Figure 4 for steel No. 2 may be taken as representative of normalized molybdenum steel except for steel No. 6 which, apparently owing to its high aluminum addition and lower manganese and carbon content, resembled the carbon steels more than it did the molybdenum steels, though there was yet some tendency for the pearlite to assume the Widmanstätten structure characteristic of molybdenum steel. Consequently the carbide plates of this steel were appreciably thicker than in the others. Some martensite, the light gray areas in Fig. 4, was found in all the normalized molybdenum steels except No. 6; this was surprising in view of the fact that the austenitizing had been carried out in $\frac{1}{2}$ by $1\frac{1}{2}$-in. bars for $\frac{1}{2}$ hr. at 1650 F. This martensite is probably to be attributed primarily to the relatively

FIG. 2.— Steel No. 9 Representing Normalized Structure of the Carbon Steel Series (× 1000). Etched in Picral.

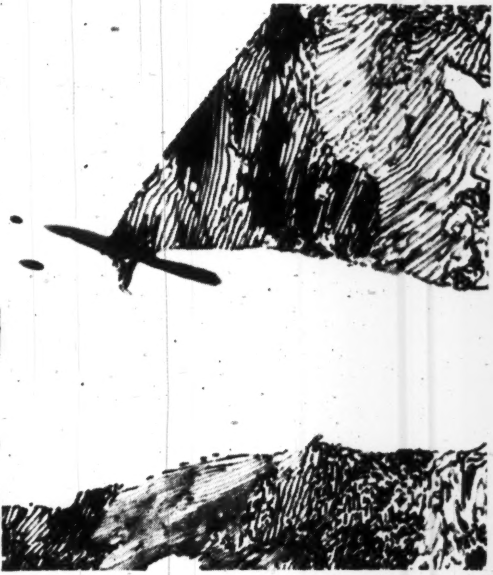


FIG. 3.—Steel No. 9 Representing Annealed Structure of the Carbon Series (× 1000). Etched in Picral.

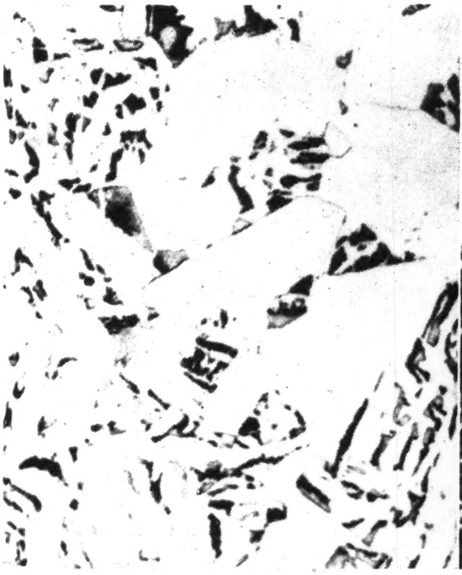


FIG. 4.—Steel No. 2 Representing Normalized Structure of the Molybdenum Steel Series (Except Steel No. 6) (× 1000). Etched in Picral.

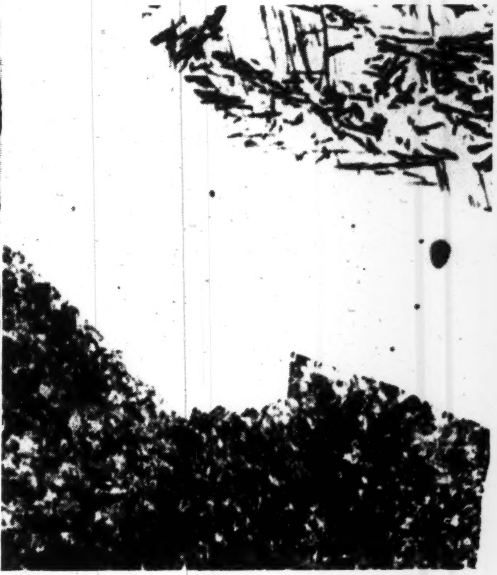
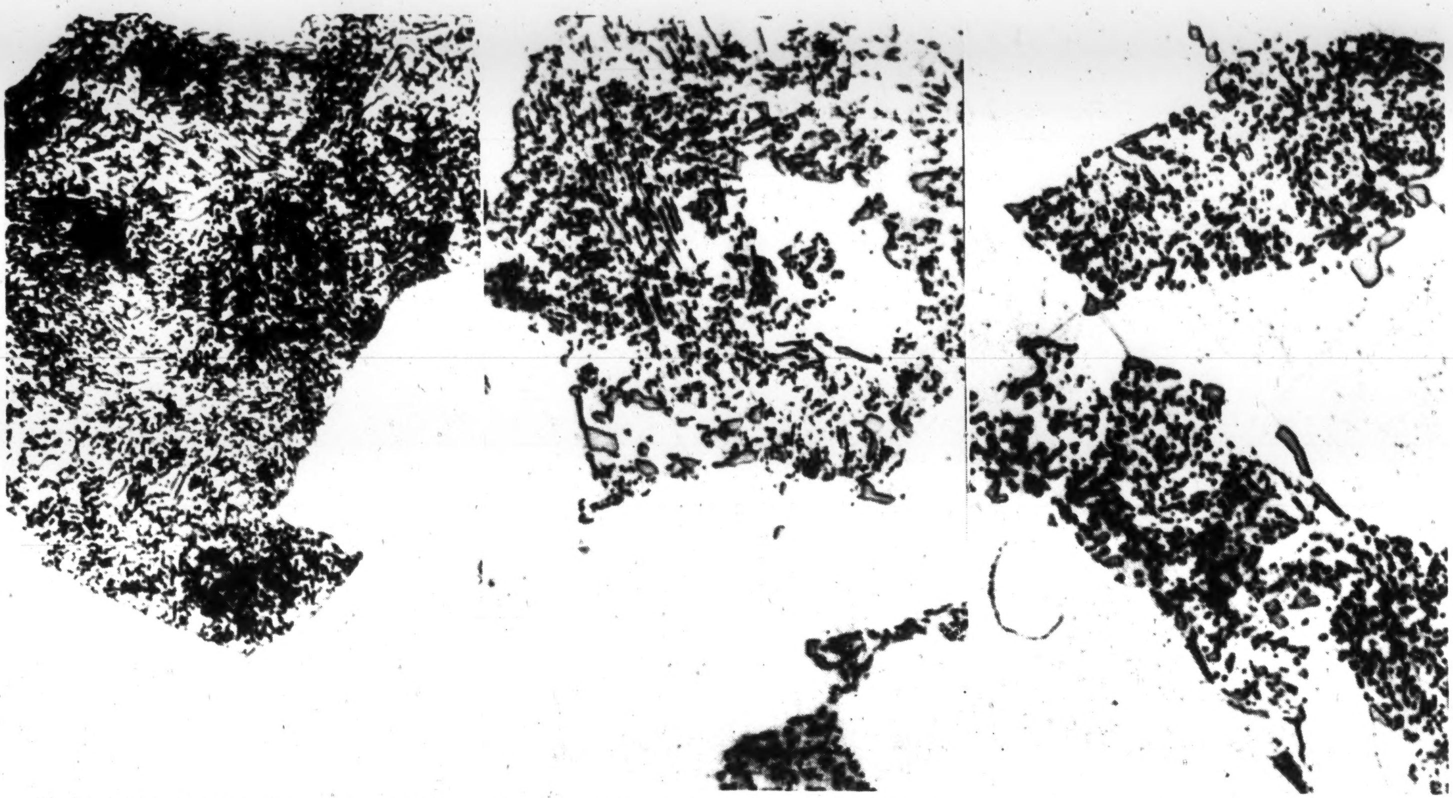


FIG. 5.—Steel No. 3 Representing Annealed Structure of the Molybdenum Series (except steel No. 6). However, the acicular structure in the upper right hand corner occurred only in steels Nos. 2, 3, and 5 (× 1000). Etched in Picral.



(*a*) Steel No. 2 after 500 hr. at 1000 F. Representing stage 1 of Spheroidization.

(*b*) Steel No. 1 after 1000 hr. at 1000 F. Representing stage 2 of Spheroidization.

(*c*) Steel No. 2 after 500 hr. at 1100 F. Representing stage 3 of Spheroidization.

FIG. 6.—Annealed steel (× 2000). Etched in Picral.

high manganese content, which incidentally is greater than permitted in A.S.T.M. pipe specification A 206,[6] though within A.S.T.M. plate specification A 204.[7] The two low-aluminum steels Nos. 3 and 5 with medium silicon content showed the least amount of martensite (other than steel No. 6) but interestingly were hardest in the normalized state. The hardness test is apparently insensitive to small amounts of martensite, and the greater hardness is to be attributed to a more favorable dispersion of the carbide patches.

Figure 5, except for the acicular structure in the upper right hand corner, is typical of the annealed structure of all the molybdenum steels. This acicular structure appeared only in the three low-aluminum steels Nos. 2, 3, and 5 and occupied the greatest volume in steel No. 3. The nature of this constituent, which resembles the lower bainite of plain-carbon steel, is not known, though its behavior on tempering and its etching characteristics strongly indicate it to be carbide. This structure has not been observed in normalized steels. Steel No. 6 in the annealed condition had a structure quite similar to that in the normalized condition, having a slightly coarser pearlite and some free carbide at the grain boundary; the similarity in structure accounts for the similarity in hardness.

Progress of Spheroidization:

A review of the literature did not reveal any established method of evaluating metallographically the degree or stage of spheroidization. Any exact quantitative method would be exceedingly tedious and hardly worth while, particularly in view of the fact that our commercial annealed and normalized structures necessarily contained varying interlamellar spacings and carbide thicknesses because they formed over a range of temperature. Accordingly, resort was had to a choice of three arbitrary stages of spheroidization: (1) first detectable change, (2) intermediate, and (3) advanced change, illustrated respectively in Figs. 6 (*a*), (*b*), and (*c*). Admittedly this choice is arbitrary and the classification depends to some extent upon the observer, but it is felt that the method is sufficiently exact for the present. The specimens were examined by two observers and yielded the data in Table III and Fig. 9.

Carbon Steels:

It is apparent that, generally speaking, the furnace-cooled specimens were more resistant to spheroidization than the normalized. This is natural since surface tension which brings about agglomeration is greater and the concentration gradients which control diffusion are steeper for the thinner carbide platelets of the normalized samples. As regards the effect of variation in deoxidation practice upon spheroidization rate, it is not possible to separate the effects of the titanium and the aluminum since both were varied simultaneously and since the differences are small. It is apparent, however from Table III and Fig. 9 that steel No. 7 with no titanium and high aluminum addition was the most resistant to spheroidization, and that No. 9 with no aluminum (except possibly as contained in the ferro-carbon-titanium addition) and high titanium addition was the least resistant.

Molybdenum Steels:

As in the carbon steels and for the same reasons, the furnace-cooled samples spheroidized more slowly than the normalized. Moreover, as a whole, the molybdenum steels were more resistant to spheroidization owing, perhaps, to the necessity for diffusion not only of carbon, but also of molybdenum, a process which occurs at an appreciably slower rate than for carbon (**23**). Examination of Table III or Fig. 9 reveals that minor differences in spheroidization rate can be brought about by differences in deoxidation practice. Thus, the addition of 1 to 1.5 lb. of aluminum per ton to silicon-killed steels accelerates spheroidization as shown by comparison of steel No. 1 with No. 2 and of No. 3 with No. 4; the steels of each pair were identically deoxidized except for the aluminum addition, and in most cases, whether normalized or annealed, the steel with aluminum addition reached a given stage of spheroidization sooner. Steel No. 6 with the largest aluminum addition (but no silicon) was most resistant of all; it seems likely that this is to be attributed to the initially coarser lamellae. Comparison of steels Nos. 2 and 3, high and low silicon, respectively, with no aluminum addition, shows the lower silicon to be the more resistant to spheroidization whether normalized or annealed. This trend is preserved in the presence of aluminum as shown by comparison of steels Nos. 4 and 1 (though the aluminum addition was not the same in both). Comparison of steel No. 5, Fe-Si-Zr, with steel No. 3, Fe-Si, and no aluminum in either case, does not reveal any very consistent difference, the former being perhaps slightly less resistant. Incidentally, it is of interest to note that steel No. 5 had 0.24 per cent chromium residual; steel No. 6 with 3 lb. of aluminum also had an appreciable, 0.17 per cent, chromium residual, but whether this has anything to do with the resistance to spheroidization of this steel is not known.

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[6] A.S.T.M. Tentative Specifications for Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 - 44 T), 1944 A.S.T.M. Book of Standards, Part I, p. 1321.

[7] A.S.T.M. Standard Specifications for Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 - 44), *ibid.*, p. 81.

"Complex Precipitate":

All of the molybdenum steels, whether previously normalized or annealed, developed during tempering the faint background precipitate in the matrix as in Figs. 6 (*c*) or 8 which is characteristic of this grade of molybdenum steel (**24**). This precipitate, about which little is known, has generally been termed "complex precipitate." It takes longer to show the lower the temperature. It appears to develop uniformly throughout a grain, though on continued tempering, it becomes scarce in the vicinity of the grain boundaries, while at the same time massive "carbides" develop there (Figs. 6 (*c*) and 8). Such behavior indicates that carbides of different composition are present. However, it is difficult to understand how the "complex precipitate," if it is molybdenum-rich, could agglomerate so rapidly since molybdenum would be expected to diffuse slowly. Perhaps what is really happening is that carbon is given up by the precipitate or by molybdenum diffusing to it and that only carbon is diffusing to form the massive "carbide." This is reasonable in that carbon can be expected to diffuse at a relatively rapid rate. There is evidently yet a great deal to be learned about the iron-carbon-molybdenum alloys. Presumably this precipitation accounts for the characteristic hardness changes on tempering these steels; moreover, both phenomena must be akin to the secondary hardening of quenched-and-tempered steels. No attempt was made to correlate the appearance of the precipitate with the beginning of rise in hardness since the precipitate is difficult to resolve in its early stages of development at which the greatest hardening can be expected to occur.

Graphitization:

Because of the recent interest in graphitization (**21**, **22**), an intensive examination of the specimens in the unetched and etched conditions was made to determine the presence of graphite. These studies were begun without any idea of the piping failure (21) in mind, and the results may have little or no bearing on that problem, since failure in that case resulted from localized graphitization near the low-temperature end of the heat-affected zone of a weld by which the pipe in question was joined to another member. It has been postulated (8) that graphitization came about because of the characteristic structures which originated in this particular region during the welding process.

An attempt, admittedly not quantitative, was made to rate the samples as to extent of graphitization; the results are listed in Table III and charted in Fig. 9. In some instances the graphite proved to be segregated, though no other evidence of segregation was apparent. Figure 7, of annealed steel No. 6 held for 1000 hr. at 1100 F., illustrates this phenomenon. There was also, in a few samples, an apparent tendency for graphite to appear near the surface as

TABLE III.—PROGRESS OF SPHEROIDIZATION AND OF GRAPHITIZATION, AS OBSERVED AFTER 5, 15, 50, 100, 300, 500, 1000, 3000, AND 5000 HR. AT TEMPERATURE.

Steel	Main Deoxidizers		Time to Reach Stage of Spheroidization, hr.									Time to Reach Stage of Graphitization, hr. (Blank spaces indicate none detected within 5000 hr. at temperature)								
	Ladle, lb. per ton	Mold, lb. Al per ton	900 F.			1000 F.			1100 F.			900 F.			1000 F.			1100 F.		
			Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
NORMALIZED SPECIMENS																				
MOLYBDENUM STEEL																				
No. 1	12.6 FeSi	1.0	100	3000	*	5	1000	3000	5	15	100									
No. 2	12.6 FeSi	0.0	3000	*	*	5	500	3000	5	50	300									
No. 3	7.7 FeSi	0.0	5000	*	*	100	3000	5000	50	300	500									
No. 4	7.7 FeSi	1.5	5000	*	*	50	500	1000	5	50	300									
No. 5	5.1 FeSiZr	0.0	3000	*	*	500	1000	3000	50	100	300									
No. 6	0.0 FeSi	3.0	5000	*	*	1000	3000	5000	100	300	1000				5000	*	*	3000	*	*
CARBON STEEL																				
No. 7	10 FeSi 0 FeCTi	1.0	1000	3000	5000	50	500	1000	15	50	300				5000	*	*			
No. 8	10 FeSi 4 FeCTi	0.5	300	1000	3000	100	500	1000	5	50	300				5000	*	*	1000	*	*
No. 9	10 FeSi 6 FeCTi	0.0	50	500	1000	5	500	1000	5	15	50					5000	*	5000	*	*
ANNEALED SPECIMENS																				
MOLYBDENUM STEEL																				
No. 1	12.6 FeSi	1.0	5000	*	*	300	1000	3000	15	100	300	5000	*	*	1000	3000	5000	300	1000	5000
No. 2	12.6 FeSi	0.0	5000	*	*	500	3000	5000	15	100	500									
No. 3	7.7 FeSi	0.0	5000	*	*	300	3000	5000	100	300	1000									
No. 4	7.7 FeSi	1.5	5000	*	*	50	300	5000	5	100	500				3000	*	*	1000	3000	*
No. 5	5.1 FeSiZr	0.0	5000	*	*	300	3000	*	50	300	500									
No. 6	0.0 FeSi	3.0	5000	*	*	500	*	*	100	300	1000				5000	*	*	1000	*	*
CARBON STEEL																				
No. 7	10 FeSi 0 FeCTi	1.0	5000	*	*	50	300	1000	15	100	500				5000	*	*			
No. 8	10 FeSi 4 FeCTi	0.5	5000	*	*	50	300	500	15	100	500				5000	*	*	3000	*	*
No. 9	10 FeSi 6 FeCTi	0.0	300	*	*	50	300	1000	15	50	300				3000	5000	*		3000	*

* Greater than 5000 hr. (limit of observation).

though its formation had been aided by inward diffusion of some agent from the atmosphere. To provide an idea of what is meant by the various stages, Fig. 8, of steel No. 1 annealed and held 5000 hr. at 1100 F., illustrates the extent of graphitization termed stage 3. The other types showed correspondingly fewer nodules in any one representative field.

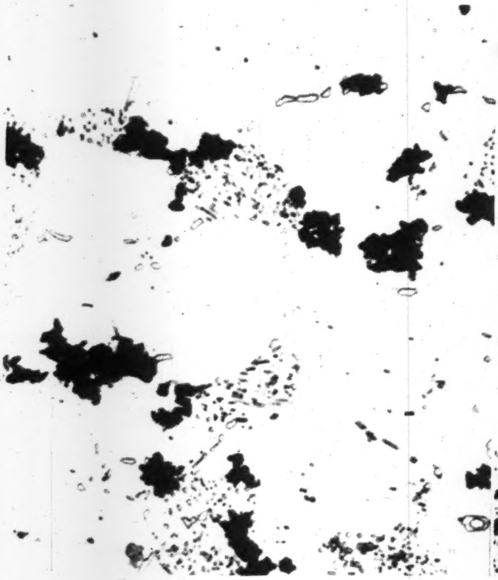

FIG. 7.—Segregated Graphite in Annealed Steel No. 6 after 1000 hr. at 1100 F. Average field in this specimen would contain very little or no graphite (× 1000). Etched in Picral.

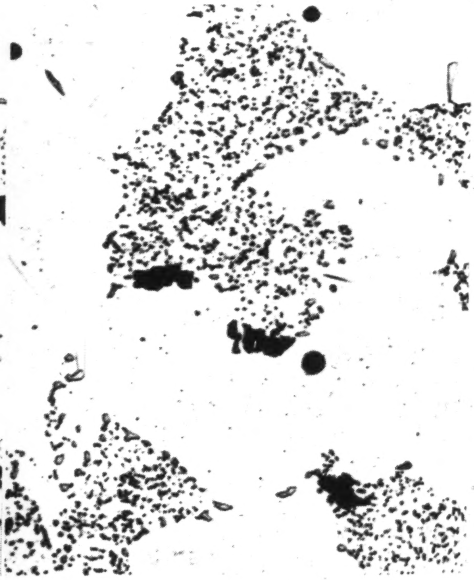

FIG. 8.—Annealed Steel No. 1 after 5000 hr. at 1100 F. Typical of stage 3 extent of graphitization (× 1000). Etched in Picral.

It is interesting that the three molybdenum steels that graphitized were those to which aluminum had been added in the mold, and that of these three, the one with highest silicon, No. 1, graphitized to the greatest extent, and that with lowest silicon, No. 6, least (in spite of having the large aluminum addition of 3 lb. per ton). It is also interesting, and perhaps unexpected, that graphitization proceeded more extensively in the annealed than in the normalized specimens; in fact, only in steel No. 6, which incidentally contained an appreciable chromium residual (0.17 per cent), was graphite detected in the normalized molybdenum steels. The use of titanium as a stabilizer of carbide and graphite inhibitor is under investigation at the present time.

In the carbon steels, the extent of graphitization or the time for its appearance was apparently independent of initial condition, that is, whether normalized or annealed; and no clear relation to deoxidation practice is apparent. In both series graphite appears generally to form faster the higher the temperature within the range studied.

In this connection it has been suggested that the type of structure developed in the carburizing test (commonly known as the McQuaid-Ehn test) may be indicative of susceptibility to graphitization according to the following scheme: steels which show a so-called "abnormal" structure are prone to graphitize, while those which show a "normal" structure are resistant to graphitization. The relationship between the two phenomena (if there proves to be such) apparently is to be attributed to the presence of aluminum or alumina which promotes both graphitization and "abnormality."

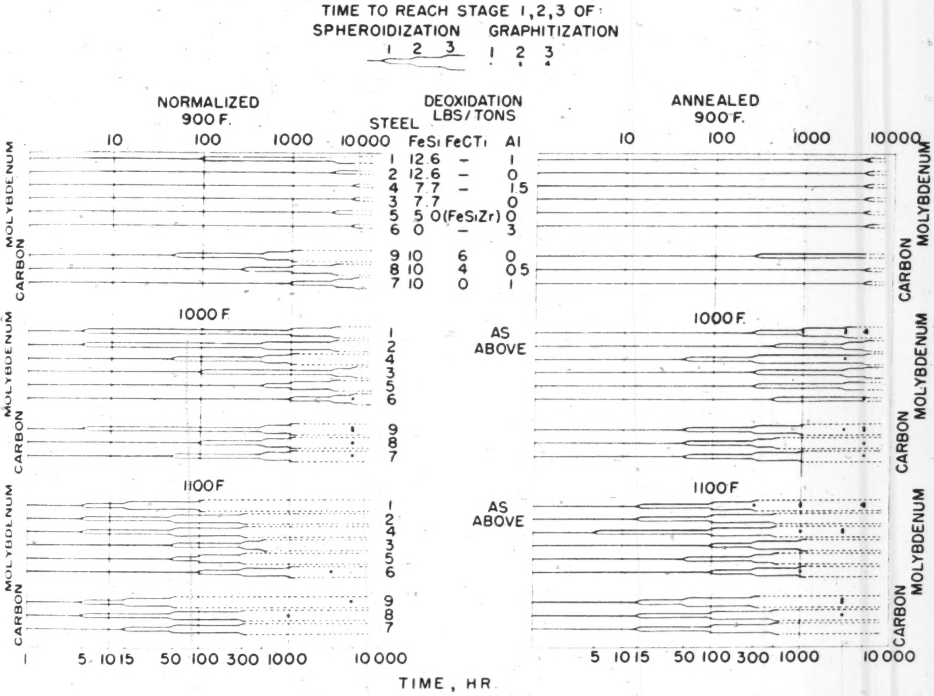

Fig. 9.—Progress of Spheroidization and Graphitization of Six Molybdenum and of Three Carbon Steels in the Normalized and the Annealed Condition at 900 F., 1000 F., and 1100 F. Observations Were Made at 5, 15, 50, 100, 300, 500, 1000, 3000, and 5000 hr., Except that (as indicated by Dotted Lines) Spheroidization Was Not Followed Beyond Stage 3.

Though, as pointed out above, our graphitization studies may not have any relationship to graphitization in weld heat-affected zones, we nevertheless thought it desirable to carry out carburizing tests on samples of each steel. The results of such carburizing tests carried out for 8 hr. at 1700 F. in a commercial compound (Houghton's Pearlite No. 50) and furnace cooled at a rate which averaged about 4 F. per minute in the temperature range 1700 to 1000 F. are given in Table I. It is apparent that for the molybdenum steels there appears to be a correlation between graphitization tendency and degree of "abnormality." That is, those which graphitized within 5000 hr. (steels Nos. 1, 4, and 6) were steels to which aluminum addition had been made and which were both fine-grained and "abnormal." Whether this is always the case, and whether "normal" steels are indefinitely resistant to graphitization, cannot be decided on the basis of our limited studies. We suspect, however, that the apparent relationship can only come about through an accelerating effect of the aluminum addition (which tends to produce "abnormality") on the rate of graphitization, not on the thermodynamic stability of graphite relative to carbide. The three carbon steels showed approximately the same degree of carburized structural normality, and in spite of their relative "normality," all graphitized. The data for both the molybdenum and carbon steels are too meager for reliable evaluation of the worth of the carburizing test as an indicator of susceptibility to graphitization.

Moreover, it remains to be seen whether simply the aluminum addition or some other direct quantity may not serve just as well as, or better than, the carburized structural normality for testing graphitization susceptibility. This test was developed for carburized steels and its results bear directly only on the problem of carburization; the degree of normality or abnormality developed is dependent upon such factors as cooling rate, alloy content, and probably such less easily controllable factors as the carburizing atmosphere. The test is more frequently used for austenite grain-size determinations, but it is to be emphasized that the grain-size values are those existant after 8 hr. at 1700 F. (if this be the treatment used) in a steel whose carbon content is now markedly different from the original. For these reasons it is to be urged that this carburizing test be limited to its field of carburizing and not used for other purposes until it is definitely proved to offer something not otherwise obtainable.

The fact that spheroidization is apparently accelerated by aluminum addition and that (in the molybdenum steels) graphitization occurred only in steels to which aluminum had been added indicates some sort of relationship between the two phenomena. This does not mean, however, that spheroidization must precede graphitization. Perhaps aluminum addition serves to increase the diffusivity of carbon and thus spheroidization and graphitization, while the alumina particles resulting from deoxidation aid somehow in nucleating graphite.

Acknowledgments:

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DISCUSSION

Mr. F. Eberle[1] (*by letter*).—The initial hardness increase which is particularly noticeable in the annealed samples on tempering at 900 to 1100 F. seems to indicate a submicroscopic precipitation phenomenon which promotes susceptibility to graphitization. We have observed in carbon-molybdenum steels removed from service installations as well as in samples subjected to long-time laboratory tests at 1000 F. that this steel is considerably more susceptible to graphitization in the annealed than in the normalized condition. As a matter of fact, we have not succeeded in producing graphite in high aluminum-deoxidized (1.8 lb. per ton) carbon-molybdenum steel fast cooled from very high temperatures (2200 F.) within 10,000 hr. at 1000 F. Severe cold deformation prior to the tempering at 1000 F. which promotes and accelerates graphitization likewise failed to produce graphite. However, when air cooled from lower temperatures (1600 to 1700 F.), graphite formed. When slowly cooled from high temperatures (50 F. per hour), this steel graphitized quite readily, but much less readily when slowly cooled from lower temperatures (1600 to 1700 F.). This behavior shows a marked similarity to the behavior of certain low-carbon steels with respect to caustic embrittlement which were studied by Houdremont of the Krupp Works in Germany. When air cooled from 1700 F., the steels were resistant to caustic embrittlement, but they became susceptible to it when slowly cooled from 1700 to 2190 F. Thus it appears that certain types of low-carbon molybdenum steels are sensitized to graphitization at elevated temperatures by certain preheat treatments.

There can be little doubt that deoxidation with suitably large amounts of aluminum renders the steels under consideration more susceptible to graphitization. This has been again demonstrated by the aluminum deoxidized carbon - molybdenum steels of the authors. Since, as the latter have pointed out, the thermodynamic stability of the carbide is not likely to be affected by the deoxidation with aluminum, it can only be what might be called the "atomic and microstructural environment" of the carbide which is affected in a manner so as to facilitate carbide dissociation. This modification of the "atomic and microstructural environment" of the carbide may include the formation of certain compounds such as oxides and nitrides of certain solubility characteristics and a change in their dispersion and distribution pattern. It may readily be seen that heat treatment may affect the latter. A change in the "atomic and microstructural environment" of the carbide may also influence carbon diffusion and thereby the rate of carbide spheroidization and the rate of graphitization. The behavior of the carbide in the so-called McQuaid-Ehn test and its modification by the nature of the deoxidation practice employed fits well into this general picture and it becomes apparent why the McQuaid-Ehn test may, with certain limitations, indicate the susceptibility to graphitization of certain steels. In this connection, it should be emphasized that the "correlation between graphitization tendency and degree of abnormality" in the McQuaid-Ehn test holds true not only for carbon-molybdenum steels, but also for plain carbon steels. The three carbon steels studied by the authors were all "slightly abnormal" and therefore sensitive to graphitization. Kerr and Eberle, in a paper presented before the 1944 Annual Meeting of The American Society for Mechanical Engineers,[2] have described the case of two plain carbon steel tubes which were totally normal in the McQuaid-Ehn test and which were found free of graphite after 8¾-yr. service at 1000 to 1020 F.

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Both spheroidization and graphitization are influenced by the nature of the carbide and its "atomic and microstructural environment." Alloy carbides, such as molybdenum and chromium carbides, probably possess a greater thermodynamic stability than the straight iron carbide and diffuse less readily than the latter. A simple calculation shows that in the molybdenum steels under discussion there is not nearly enough molybdenum to convert the whole carbon into molybdenum carbide, and the reason for the greater resistance to graphitization of these steels as compared with the corresponding plain carbon steels therefore cannot be sought in a greater thermodynamic stability of the carbide present. Consider also the fact that these steels develop at temperatures where graphitization occurs a molybdenum-containing "complex precipitate" in the matrix. Obviously, it is not a greater thermodynamic stability of the carbide in these steels which gives them greater resistance to graphitization since only a relatively small part of the carbide can be a molybdenum carbide, but the modification of the "atomic and microstructural environment" by the presence of molybdenum. Similarly, if we add to these 0.5 per cent molybdenum steels 0.5 per cent chromium, we not only convert part of the carbide into thermodynamically more stable molybdenum and chromium containing carbide, but we also change the "atomic and microstructural environment" of the carbide in a manner which effectively delays the breakdown of the remaining iron carbide into graphite.

MESSRS. G. V. SMITH, R. F. MILLER AND C. O. TARR (*authors' closure by letter*).—We are happy to have Mr. Eberle corroborate our finding that 0.5 per cent molybdenum steel graphitizes at a faster rate in the annealed than in the normalized condition. Whether a presumed submicroscopic precipitation phenomenon which causes the initial increase in hardness promotes susceptibility to graphitization as Mr. Eberle postulates, we do not know. We suspect, however, that this precipitation occurs, at least in part, not at the tempering temperature, but on or after cooling therefrom; that is, we are dealing with the well-known quench-aging effect in low-carbon steels, the samples having been air cooled from the tempering temperature and therefore being more liable to aging than when originally furnace cooled. This aging is therefore apparently of a different sort than that occurring in molybdenum steel after longer tempering times. We regret that we did not discuss this adequately in the paper.

As Mr. Eberle states, there can be little doubt that deoxidation with a sufficiently large amount of aluminum renders these low-alloy steels more susceptible to graphitization. How this effect is brought about and its relation to the associated phenomena of fine grain size and "abnormality" in the carburizing test is not known. We believe that further experimentation directed at discovering the fundamental factors involved is very desirable. In our opinion the most important single aspect of the problem is to determine what factors influence the nucleation of graphite. Once graphite has been nucleated, there would seem to be little difficulty in the way of its further growth since carbon diffuses with relative ease. The problem of nucleation is not a simple one.

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[2] H. J. Kerr and F. Eberle, "Graphitization of Low-Carbon and Low-Carbon-Molybdenum Steels," *Welding Journal*, Research Supplement, February and June, 1945.

We have recently obtained further data[3] on the graphitization of plain carbon steel of interest in regard to the relation between "abnormality" in the carburizing test and graphitization susceptibility. These data, for ten different carbon steels, show that those which graphitized were abnormal, but not all those which were abnormal graphitized.

If the alloy carbide in a 0.5 per cent molybdenum—0.15 per cent carbon steel can be assumed to be represented by the formula Mo_2C, it is true that there is insufficient molybdenum to combine with the carbon. However, the available data reviewed in the paper, particularly that of Bowman and associates, show that when alloying elements are present, we do not have the simple iron carbide, Fe_3C, nor the simple alloy carbide, as typified by Mo_2C. Apparently in all or most carbides there is a mutual intersolubility of the elements. That is, the atoms of the first alloy addition tend to enter into the iron carbide lattice to yield a carbide which can be represented by $(Fe,X)_3C$. After some concentration, dependent upon the particular element, has been exceeded, a new type of carbide appears, but one which also dissolves or contains iron atoms. Presumably the thermodynamic stability of $(Fe,X)_3C$ or other carbide depends upon the relative amounts of Fe and X. In some instances, the mutual intersolubility may be very slight, but this does not appear to be the case for molybdenum steels. As for the "atomic and microstructural environment" of which Mr. Eberle writes, this cannot be distinguished, in part, from thermodynamic stability since when we speak of iron carbide as being unstable, or of another carbide as being stable, with respect to graphite, we mean that this is true in the atomic environment in which the carbide exists. Of course, the rate at which a thermodynamically unstable carbide will revert to stable graphite depends upon the rates of nucleation and growth. Of these, we believe that the rate of nucleation is the controlling factor, as mentioned earlier, and that it is influenced greatly by the microstructural environment.

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[3] G. V. Smith, S. H. Brambir, and W. G. Benz, "Comparative Graphitization of Some Low-Carbon Steels with and without Molybdenum and Chromium," a paper presented at the annual meeting of Am. Soc. Mechanical Engrs., November, 1945.

A STUDY OF SIZE EFFECT AND NOTCH SENSITIVITY IN FATIGUE TESTS OF STEEL

BY H. F. MOORE[1]

SYNOPSIS

In this paper the effect of size of specimen on the endurance limit of steel specimens (or parts) is studied from a slightly different viewpoint from that of the Third Progress Report on Size Effect, which is found in an appendix to the 1944 Report of the Research Committee on Fatigue of Metals (**1**).[2] In addition to the test data in the Third Progress Report on Size Effect, the test results reported by Moore and Jordan (**2**) in the *Proceedings* of the Fifth International Congress of Applied Mechanics are used as a basis for this study.

The size effect in plain (unnotched) specimens is computed on assumption that a fatigue specimen which fails under cycles of reversed flexure behaves as if a fatigue crack started slightly *below* the surface of the specimen, where the nominal stress is slightly lower than that *at* the surface. The further assumption is made that at this point below the surface the nominal stress at failure is independent of size of specimen, and that the depth of this assumed starting point below the surface is also independent of the size of specimen. The test results for six different steels gave endurance limits deviating from the results of computation based on the above assumptions ranging from +8.50 per cent to −7.05 per cent with a mean deviation of 4.19 per cent.

The second part of the report takes up the problem of notch sensitivity of the various steels tested, using the methods and graphical solutions given by Neuber (**3**). In Neuber's diagrams the determination of the actual strength reduction due to a notch from the theoretical (or geometrical) stress-concentration factor involves a constant ρ' (in inches) which Neuber calls a dimension of an elementary structural unit of a metal, but which the author of this paper has found it preferable to regard as an inverse measure of notch sensitivity. It was found that the formula

$$\rho' = 0.2\left(1 - \frac{S_y}{S_u}\right)^3 \times \left(1 - \frac{0.05}{d}\right)$$

gave values of ρ' (in inches) which, when used in the Neuber diagrams, gave computed values of strength reduction factor k' which agreed with the results of actual fatigue tests of the six types of steel studied with a maximum deviation of 8.2 per cent. In the above formula S_y denotes the yield strength of the steel, S_u the tensile strength of the steel, and d the critical diameter (in inches) at the root of the notch.

In connection with the tests there was discovered to be an appreciable difference between bright-annealed S.A.E. 1035 steel polished before annealing and the same steel lightly machined and polished after annealing. The fatigue strength of the steel polished after annealing was greater than that of the steel polished before annealing, and the notch sensitivity was less.

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[1] Research Professor of Engineering Materials, Emeritus, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 521.

INTRODUCTORY: TESTING MACHINES AND SPECIMENS

The tendency of test specimens or machine parts with large cross-sections to fail under repeated loading under lower computed stresses than do specimens or machine parts with smaller cross-sections is a well-established fact, and in the First, Second, and Third Progress Reports,[3] published in connection with annual reports of the Research Committee on Fatigue of Metals, a considerable amount of test data on this "size effect" has been given. This paper presents further data, and a different approach to the problem of size effect from that given in the three progress reports, and also presents a proposed method for determining a notch sensitivity constant for use in the Neuber method of computing the actual fatigue strength-reduction factor, k', caused by notches of different dimensions and shapes in parts subjected to repeated stress.

The testing machines used for the fatigue tests listed in this paper were all simple cantilever rotating-beam machines, and the critical dimensions and general shape of the specimens used may be determined from the tabular material and from Figs. 2 and 3.

The metals studied included the three types of steel (with two heat treatments of one type) reported in the Third Progress Report (**1**), and also two types of steel tested by Moore and Jordan (**2**).

SIZE EFFECT FOR UNNOTCHED SPECIMENS

In the Third Progress Report on Size Effect in Fatigue Tests (**1**), published in the 1944 report of the Research Committee on Fatigue of Metals, this problem was attacked on the assumption that in all metals there are numerous small "inherent" defects which act as stress-raisers and that their effect in causing stress concentration, and consequent strength reduction, may be regarded as equivalent to that of some small semicircular notch. By a trial and error study of the test data in that report, it was found that if the effect of the inherent defects were considered to be equal to that of a semicircular notch 0.006 in. in diameter, the endurance limit of each of the steels tested, assumed to be free of such stress concentration, would be independent of size of specimen, that is, an endurance limit for "flawless" steel, independent of size of (unnotched) specimen, would be found.

However, it has not yet been found possible to identify the size of the "equivalent" semicircular notch in a metal by any other means than by trial and error methods involving a large number of fatigue tests.

In this paper the attack on the problem is quite different from that above, and was suggested by R. E. Peterson during a meeting of the Research Committee on Fatigue of Metals. It is assumed that a fatigue fracture behaves as if the fatigue crack starts not at the surface of a polished specimen but at a small distance h below it. The value of h is assumed to be a constant of the metal, independent of the size of the specimen, and the computed tensile stress S_e at depth h is also assumed to be independent of the size of specimen.

These assumptions seem, at first glance, to be of dubious validity. The idea that the critical point where fracture starts is on the *surface* of a flexural test specimen, where the nominal tensile stress is greatest, is firmly fixed in our minds. However a consideration of the nature of the metal at and just below the surface of a polished specimen makes the assumption that fracture may start very close to the surface seem not unreasonable. The polishing of the surface of a specimen slightly cold works and strengthens a thin zone or "skin" of the metal. How much of this strengthening is due to compressive stresses set up in this skin and how much to rearrangements of the crystalline structure of the metal in this cold-worked zone is uncertain. However the net effect is the strengthening of the outer layers of the metal, so that fracture may well start slightly below the surface of a polished specimen in the weaker metal under the cold-worked zone.

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 145 (1942); Vol. 43, p. 109 (1943); Vol. 44, p. 137 (1944).

Another way of considering this matter is suggested by the explanation of size effect proposed (by Morkovin) in the Third Progress Report on Size Effect. He assumed that in all metals there are many "inherent" defects, probably microscopic for the most part. These defects act to reduce the fatigue strength of the metal, and their strength-reducing effect is equivalent to that of a small semicircular notch at the surface of a specimen. For the steels studied in the Third Progress Report, the "equivalent" semicircular notch was found to be 0.006 in. deep. It seems, not unreasonable to assume that the actual fracture may start at the *bottom* of some "inherent" defect at the surface, or at some such defect slightly below the surface.

COMPUTATION OF ENDURANCE LIMITS FOR DIFFERENT SIZES OF UNNOTCHED SPECIMENS

Figure 1 shows the stress distribution in a round specimen under bending. Let S_e' represent the stress at the surface—the endurance limit as given directly from the results of a series of fatigue tests of similar specimens. Let S_e represent the nominal longitudinal stress at the distance h below the surface, where the fracture is supposed to start, and let d represent the thickness, or diameter of the piece.

Then:

$$S_e = S_e' \frac{d/2 - h}{d/2} = S_e'\left(1 - \frac{2h}{d}\right) \ldots (1)$$

And

$$S_e' = \frac{S_e}{1 - 2h/d} \ldots\ldots\ldots\ldots (2)$$

Now if there are two sets of unnotched fatigue specimens of the same metal, one with diameter d' and the other with diameter d'', and if the corresponding nominal endurance limits (surface stresses) are found by test to be S_e' and S_e'', then:

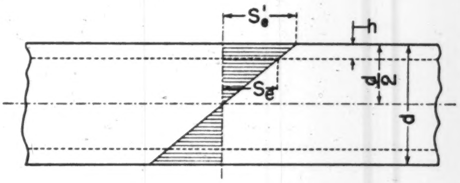

FIG. 1.—Nominal Stresses S_e and S'_e and Depth h in an Unnotched Specimen Under Bending.

$$S_e = S_e'\left(1 - \frac{2h}{d'}\right) = S_e''\left(1 - \frac{2h}{d''}\right)$$

and S_e and h are unknown.

From:

$$S_e'\left(1 - \frac{2h}{d'}\right) = S_e''\left(1 - \frac{2h}{d''}\right)$$

$$h = \frac{S_e' - S_e''}{\dfrac{2S_e'}{d'} - \dfrac{2S_e''}{d''}} \ldots\ldots\ldots\ldots (3)$$

and from Eq. 1

$$S_e = S_e'\left(1 - \frac{2h}{d'}\right) \text{ or } S_e''\left(1 - \frac{2h}{d''}\right) \ldots (4)$$

This means that if the assumption of the constancy of h and of S_e for any metal is accurate, regardless of size of specimen, their values can be determined from two series of fatigue tests of unnotched bars of different sizes, remembering that it is important to have surface conditions as nearly alike as is possible in the two cases. With h and S_e known, it is possible to predict for any size of specimen or piece the value of the surface stress, S_e', that is the nominal value of the endurance limit corresponding to any diameter.

An illustrative example may make the procedure more clear.

Given: Specimen A' with $d' = 0.150$ in. and endurance limit by test = 40,000 psi.
and
Specimen A'' with $d'' = 0.400$ in. and endurance limit by test = 36,000 psi.
To determine: Value of h and of S_e for all specimens of that metal, and the nominal endurance limit S_e''' for a specimen 1 in. in diameter ($d''' = 1.00$)

From Eq. 3,

$$h = \frac{40{,}000 - 36{,}000}{\dfrac{2 \times 40{,}000}{0.150} . \dfrac{2 \times 36{,}000}{0.400}}$$

$$= \frac{4000}{353{,}333} = 0.0113 \text{ in.}$$

From Eq. 4,

$$S_e = 40{,}000\left(1 - \frac{2 \times 0.0113}{0.150}\right) = 33{,}970 \text{ psi.}$$

Or

$$S_e = 36{,}000\left(1 - \frac{2 \times 0.0113}{0.400}\right) = 33{,}970 \text{ psi.}$$

Then from Eq. 2 for a specimen 1 in. in diameter

$$S_e''' = \frac{33{,}970}{1 - \dfrac{2 \times 0.0113}{1.000}} = 34{,}760 \text{ psi.}$$

The results of two rather extensive series of fatigue tests of specimens of different sizes and of different kinds of steel were studied for checking the reliability of the assumptions involved in using h and S_e. One series (hereafter called series I) is reported in the *Proceedings* of the Fifth International Congress of Applied Mechanics (2), and the other (hereafter called series II) is reported in the 1944 *Proceedings* of the A.S.T.M. (1). All fatigue tests were made in rotating-cantilever fatigue test-

TABLE I.—CHEMICAL COMPOSITION, HEAT TREATMENT, AND MECHANICAL PROPERTIES OF STEELS USED IN SIZE EFFECT TESTS.

Steel	Heat Treatment	Chemical Composition, per cent								Mechanical Properties			
		Carbon	Manganese	Silicon	Chromium	Nickel	Molybdenum	Sulfur	Phophorus	Yield Strength, psi.	Tensile Strength, psi.	Elongation, per cent	Reduction of Area, per cent
S.A.E. 1020 (series II).....	Tested as rolled	0.22	0.46	0.20	...	...	...	0.033	0.014	32 300[a]	62 000	28.0	59
S.A.E. 1020 (series I)......	Strain relieved at 450 F.	0.20	0.50	...	...	...	...	0.033	0.011	34 900[a]	59 900	37.2	64
S.A.E. 1035 (series II).....	Tested as rolled	0.34	0.78	0.24	...	...	...	0.028	0.016	47 200[a]	87 600	25.0	50
S.A.E. 1035 (series II).....	Bright annealed in vacuum at 1500 F.	0.34	0.78	0.24	...	...	...	0.028	0.016	43 400[a]	77 600	27.5	54
S.A.E. 2345 (series I)......	Water quenched from 1475 F., drawn at 1050 F.	0.46	0.66	0.197	...	3.32	...	0.020	0.019	99 500[b]	125 500	22.7	61
S.A.E. X4130 (series II).....	Quenched and drawn to approx. 300 BHN	0.31	0.55	...	1.08	...	0.20	0.019	0.017	115 600[b]	141 800	17.6	60

[a] Yield point by drop of beam or halt of load-indicating pointer.
[b] Yield strength by 0.2 per cent offset from straight-line portion of stress-strain diagram.

TABLE II.—VALUES OF h AND OF S_e FROM RESULTS OF FATIGUE TESTS OF UNNOTCHED SPECIMENS.

h = depth below the surface of the specimen at which the fatigue crack is assumed to start in inches,
S'_e = endurance limit determined by tests of fatigue specimens with diameter d' (inches), and
S''_e = endurance limit determined by tests of fatigue specimens with diameter d'' (inches).

$$h = \frac{S'_e - S''_e}{2S'_e/d' - 2S''_e/d''}$$

Metal	(1) d', in.	(2) d'', in.	(3) S'_e, psi.	(4) S''_e, psi.	(5) $2S'_e/d'$, lb. per cu. in.	(6) $2S''_e/d''$, lb. per cu. in.	(7) (5)-(6) lb. per cu. in.	(8) (3)-(4) psi.	(9) $h = \frac{(8)}{(7)}$, in.
S.A.E. 1020 steel, as rolled	0.125	0.500	34 000	28 900	545 000	129 400	415 600	5 100	0.0119
S.A.E. 1020 steel, strain relieved	0.160	0.500	29 000	28 000	362 000	112 000	250 000	1 000	0.0040
S.A.E. 1035 steel, as rolled	0.125	0.500	39 000	35 000	625 000	140 000	485 000	4 000	0.0082
S.A.E. 1035 steel, bright annealed, but not polished after anneal	0.125	0.500	35 000	31 500	560 000	126 000	434 000	3 500	0.0081
S.A.E. 2345 steel, heat treated	0.125	0.500	70 250	66 500	1 124 000	266 000	858 000	3 750	0.0044
S.A.E. X4130 steel, heat treated	0.125	0.500	75 400	65 000	1 205 000	260 000	945 000	10 400	0.0111
								Avg.	0.00795

TABLE III.—PREDICTION OF ENDURANCE LIMIT FOR UNNOTCHED SPECIMENS WITH VARIOUS DIAMETERS AND CHECK WITH FATIGUE TEST RESULTS.

S'_e = the extreme fiber stress at endurance limit for specimens with diameter d'. This is the ordinary endurance limit as computed from fatigue tests.
S_e = the endurance limit stress, independent of size of specimen, at the depth h below the surface, where the fatigue crack is assumed to start. This may be thought of as the endurance limit for direct tension and compression tests, or as the endurance limit in flexure for specimens so large that the stress gradient over a cross-section approaches zero. Values of S_e were determined from fatigue test results on 0.25-in. specimens.
h = the distance below the surface of the specimen at which the fatigue crack is assumed to start. In this table the value of 0.008 in. is taken for h. This is the approximate average value of h determined as shown in Table II.

Metal	(1) Diameter, d', in.	(2) S'_e by test, psi.	(3) $1-2h/d'$	(4) S_e from Tests of ¼-in. Specimens, psi.	(5) S'_e, psi.	(6) Deviation of (5) from (2), psi.	(7) Deviation of (5) from (2), per cent
S.A.E. 1020 steel, as rolled (series II)	0.125	34 000	0.872		34 400	+400	+1.17
	0.250	32 000	0.936	30 000	32 000	0	0
	0.500	28 900	0.968		31 000	+2100	+7.28
	1.000	28 200	0.984		30 600	+2400	+8.50
	1.875	28 200	0.992		30 300	+2100	+7.42
S.A.E. 1020 steel, strain relieved (series I)	0.160	29 000	0.900		30 200	+1200	+4.12
	0.250	29 000	0.936	27 100	29 000	0	0
	0.500	28 000	0.968		28 000	0	0
	1.000	28 000	0.984		27 600	−400	−1.43
	1.875	28 000	0.992		27 300	−700	−2.50
S.A.E. 1035 steel, as rolled (series II)	0.125	39 000	0.872		41 700	+2700	+6.95
	0.250	39 000	0.936	36 400	39 000	0	0
	0.500	35 000	0.968		37 600	+2600	+7.42
	1.000	34 400	0.984		37 000	+2600	+7.56
	1.875	34 000	0.992		36 600	+2600	+7.65
S.A.E. 1035 steel, bright anneal, polished before annealing (series II)	0.125	35 000	0.872		36 500	+1500	+4.28
	0.250	34 000	0.936	31 800	34 000	0	0
	0.500	31 500	0.968		32 900	+1400	+4.43
S.A.E. 2345 steel, heat treated (series I)	0.125	70 250	0.872		71 500	+1250	+1.79
	0.160	70 750	0.900		69 500	−1250	−1.77
	0.250	66 750	0.936	62 500	66 750	0	0
	0.300	71 000	0.947		66 000	−5000	−7.05
	0.500	66 500	0.968		64 500	−2000	−3.01
	0.875	64 000	0.982		63 700	−300	−0.47
	1.500	66 500	0.989		63 300	−3200	−4.82
S.A.E. X4130 steel, heat treated (series II)	0.125	75 400	0.872		74 800	−600	−0.80
	0.250	69 800	0.936	65 200	69 800	0	0
	0.500	65 000	0.968		67 400	+2400	+3.68
	1.000	63 600	0.984		66 400	+2800	+4.40
	1.750	63 600	0.991		65 700	+2100	+3.30

Mean deviation, predicted values of endurance limit from test values (disregarding sign) = 4.19 per cent.
Maximum deviations, +8.50 and −7.05 per cent.

ing machines (complete reversal of bending stress) and the sizes of specimens ranged from 0.125 in. to 2.0 in. in diameter. Table I gives the chemical composition, the heat treatment and the mechanical properties of the steels tested.

For each steel the values of h and S_e were determined from the fatigue limits obtained for the specimens 0.125 in. and 0.500 in. in diameter (except that for one steel, S.A.E. 1020, series I, the sizes used were 0.160 in. and 0.500 in. in diameter.) These small sizes were used because they were in the range of sizes within which the size effect was most marked and because it seemed desirable to see whether small specimens could be used to predict size effect. Table II shows the values of S_e and of h determined for the various steels. It was found by some trials of other sizes to determine these values that a considerable variation in h caused but little variation in S_e.

This fact, in connection with the lack of any apparent systematic variation in the value of h, suggested the use of the average value of h for *all* the steels tested for the prediction of endurance limit of large specimens from the endurance limit of smaller specimens. The approximate average value of h was 0.008 in., and the prediction of endurance limit for larger specimens was based on test results for specimens 0.250 in. in diameter—a size of specimen which can be tested in the R. R. Moore type of rotating-beam testing machine or in small rotating-cantilever machines.

Table III shows the comparison of predicted results and results by test for the different sizes of the different steels tested. The greatest deviations of predicted endurance limit from endurance limit by test were $+8.50$ and -7.05 per cent, and the average deviation, disregarding sign, was 4.19 per cent. These results give promise of usefulness for this method of predicting fatigue strength of parts up to 2 in. in diameter (or thickness) from the results of tests of small polished specimens. However, with our present knowledge, and in view of the failure of some much larger specimens at very low stress, it would be unwise to extrapolate values much beyond 2 in. in diameter. Similar tests are in progress on at least one of the non-ferrous metals. In the appendix to the 1941 Report of the Research Committee on Fatigue of Metals some data were given which showed little "size effect" for specimens of aluminum-copper alloy 17S-T (4).

STRENGTH REDUCTION DUE TO NOTCHES

The determination of the reduction of the fatigue strength on account of notches (holes) is proposed, using a slight modification of the method used by Neuber (3). His method begins by determining the "theoretical" or "geometrical" stress-concentration factor for a specimen with a given shape and size, using the formulas and techniques of the mathematical theory of elasticity. His analysis is very complex, but he has been able to express the results in the form of quite simple diagrams. The Neuber diagram for bending stresses in a solid circular bar is shown in Fig. 2, and directions for its use are given in the caption of that figure. For other types of stressing, the curve *OB* has a different shape, and for some cases the scale for values of $\sqrt{t/\rho}$ is changed, and for hollow specimens a special auxiliary diagram is given in Neuber's book (3).

Neuber also gives formulas and a diagram for taking account of the fact that actual metals are not perfectly homogeneous, not perfectly isotropic, and that Hooke's law ceases to hold, at least above a certain limiting stress. Before discussing the method of modifying the value of k_t to obtain the value of the actual strength-reduction factor, k', three general tendencies may be noted:

1. The "theoretical" or "geometrical" stress-concentration factor, determined

from the Neuber diagram, is in this paper denoted by k_t. The ratio of actual fatigue strength determined by test for unnotched specimens to the fatigue strength of notched specimens of the same critical cross-section is, in this paper, called the "strength-reduction factor," and is denoted by k'. All available data indicate that k' is less than k_t.

2. It has often been observed, for steel at least, that, as the tensile strength is increased, the value of the actual strength-reduction factor due to a notch, k', approaches the value of k_t.

3. In general, the larger the specimen the lower its endurance limit in pounds per square inch, (or kilograms per square centimeter). However, in view of the very low strengths developed by single crystals of metal, or in tests of specimens made up of a few large crystals (**5**), it seems probable that a minor factor, acting in a contrary direction, is present, due to the relatively greater proportion of area of cross-section occupied by a single crystal in a small specimen than the proportion occupied by a single crystal in a large specimen (**5**).

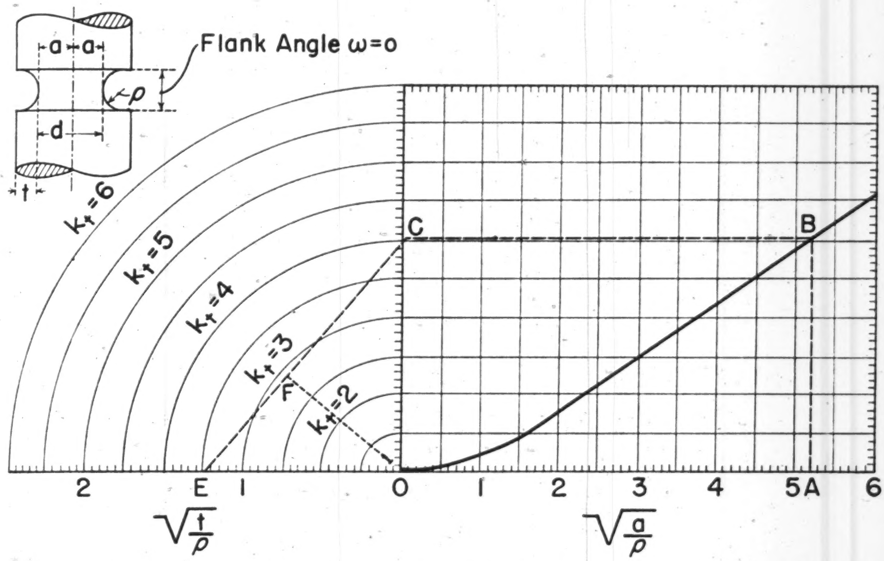

FIG. 2.—Neuber Diagram for Determining k_t for a Circular Solid Beam with Flank Angle = 0.

Solution of Illustrative Problem:

Given: $d = 2.164$ in., $a = \frac{1}{2}d = 1.082$ in., $t = 0.0625$ in., $\rho = 0.04$ in.

Then $a/\rho = 1.082/0.04 = 27.05$ and $\sqrt{a/\rho} = 5.20$ and $t/\rho = 1.56$; $\sqrt{t/\rho} = 1.25$.

To determine k_t the "theoretical" or "geometrical" stress-concentration factor.

Enter the diagram at A where $\sqrt{a/\rho} = 5.20$. Draw a vertical straight line to intersect the Neuber diagram at B. Then draw a horizontal straight line to C and a straight line from C to E, where $\sqrt{t/\rho} = 1.25$.

Then the length of the straight line OF, perpendicular to CE measures the value of k_t. By the scale across the quarter circles centering on O (this scale begins with 1 not with zero) the line OF scales 2.9. $k_t = 2.9$.

THE NEUBER REDUCTION DIAGRAM AND THE VALUE OF THE FACTOR ρ'

Neuber recognized that k' is smaller than k_t, and he suggested formulas and a diagram for determining the value of k' from the value of k_t, factors in the operation being: (1) ρ, the radius (in inches) at the bottom of the notch, (2) a factor ρ' (in inches) thought of by Neuber as some dimension of an "elementary structural unit" (3),[4] and (3) the flank angle ω of the notch (see Fig. 3).

Figure 3 shows the Neuber reduction diagram, directions for its use being given in the caption. All the notched specimens whose test results are later referred to in this paper had a flank angle, ω, of zero, and in that case the strength-reduction k' may be determined by the formula

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[4] However in this paper ρ' is considered rather as an inverse measure of notch sensitivity (notch sensitivity high, ρ' small).

$$k' = 1 + \frac{k_t - 1}{1 + \sqrt{\rho'/\rho}} \quad \ldots\ldots\ldots (5)$$

However, the use of the Neuber reduction diagram is quicker than the use of Eq. 5, when that equation does apply, and is usually sufficiently accurate for practical purposes.

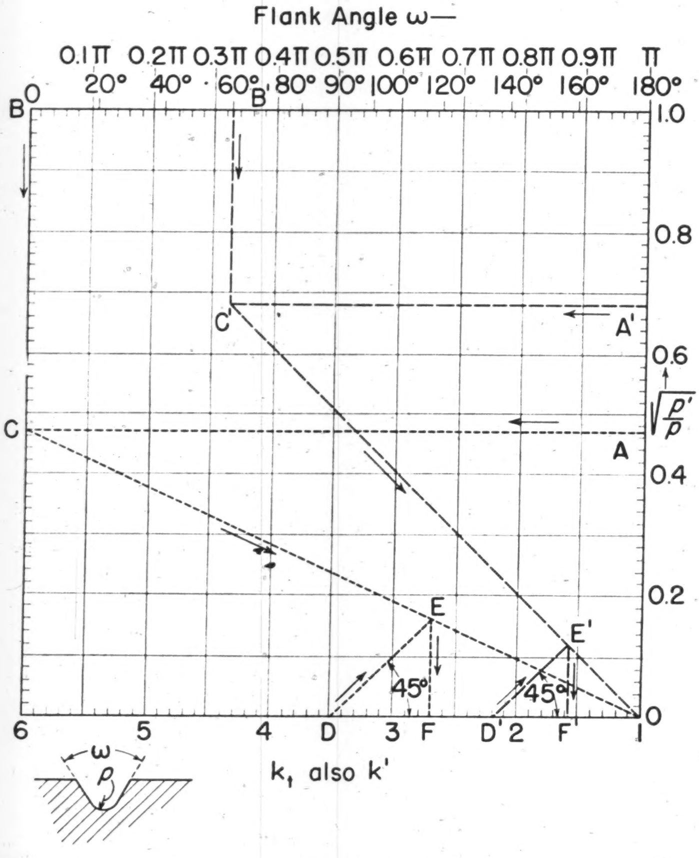

FIG. 3.—Neuber Reduction Diagram for Determining Strength-Reduction Factor k' from "Theoretical" Stress-Concentration Factor k_t.

Solution of Two Typical Problems.

I. *Given* $\sqrt{\rho'/\rho} = 0.47$; Flank angle, ω, = 0; $k_t = 3.50$.
To determine the strength-reduction factor k'.

Enter the diagram at *A* where $\sqrt{\rho'/\rho} = 0.47$. Draw *AC* horizontally to *C* where the flank angle abscissa = 0. Draw *CO* to the zero of the scale for $\sqrt{\rho'/\rho}$. Enter the diagram at *D* where $k_t = 3.50$ and draw *DE* at 45 deg. with the horizontal intersecting *CO* at *E*. Draw *EF* vertically intersecting the base line at *F*. Then *OF* scales 2.7 and $k' = 2.7$.

II. *Given* $\sqrt{\rho'/\rho} = 0.68$; Flank angle $\omega = 60$ deg. or $\pi/3$ radians; $k_t = 2.2$.
To determine the strength-reduction factor k'.

Enter the diagram at *A'* where $\sqrt{\rho'/\rho} = 0.68$. Draw *A'C'* horizontally. Enter the diagram at *B'* where, ω, the flank angle equals 60 deg. or $\pi/3$, and draw *B'C'* vertically to intersect *A'C'* at *C'*. Draw a straight line *C'O* to the zero of the scale for $\sqrt{\rho'/\rho}$. Enter the diagram at *D'* where $k_t = 2.2$ and draw *D'E'* at 45 deg. with the horizontal to intersect *C'O* at *E'*. Draw *E'F'* vertically intersecting the base line at *F'*. Then *OF'* scales 1.58 and $k' = 1.58$.

The determination of the constant ρ' for any metal is the principal difficulty in the use of the Neuber reduction diagram. At first glance it seems that ρ'

might well be a function of the grain size of the metal, and it is not impossible that it may be a function of the size of the original austenite grain size in a steel, but this is by no means a well-established conclusion. It seems reasonable to suppose that the increased strength shown by the fact that k', the actual strength-reduction factor, is less than the "theoretical" (or "geometrical") stress-concentration factor is due in large part to the resistance to fracture of a metal under repeated plastic strain. This increased resistance might well be some function of the ratio between tensile strength, S_u, and yield strength, S_y. The function

$$c\left(\frac{S_u - S_y}{S_u}\right)^3 = c\left(1 - \frac{S_y}{S_u}\right)^3$$

was tried out to see whether with the assumption of such a value for ρ' in Fig. 3 it would give good agreement between computed values of k' and values of k' determined directly by fatigue tests. Using a value of c of 0.15 in., a fair agreement between computed values and test values of k' was found for the tests of all the steels whose test results were given in the two series of tests referred to earlier in this paper.

TABLE IV.—MECHANICAL PROPERTIES, DIMENSIONS AND FACTOR ρ' FOR DIFFERENT SIZES OF STEELS TESTED.

$$\rho' = 0.2\ (1 - S_y/S_u)^3 \times (1 - 0.05/d)$$

	Diameter of Specimen d, in.	S.A.E. 1020 Steel		S.A.E. 1035 Steel		S.A.E. 2345 Steel, Heat Treated	S.A.E. X4130 Steel, Heat Treated
		As Rolled	Strain Relieved	As Rolled	Bright Anneal		
MECHANICAL PROPERTIES AND RATIOS							
Test Series	...	II	I	II	II	I	II
Yield Strength, S_y, psi.	...	32 300	34 900	47 200	43 400	99 500	115 600
Tensile Strength S_u, psi.	...	62 000	59 900	87 600	77 600	125 500	141 800
$\frac{S_y}{S_u}$	...	0.520	0.583	0.540	0.560	0.793	0.818
$1 - S_y/S_u$	...	0.480	0.417	0.460	0.440	0.207	0.182
$(1 - S_y/S_u)^3$	...	0.1106	0.0725	0.0973	0.0852	0.0089	0.0060
VALUES OF ρ', IN.							
	0.125	0.0133	0.0087	0.117	0.102	0.00107	0.00072
	0.160	...	0.0100	...	...	0.00123	...
	0.250	0.0177	0.0116	0.0156	0.0136	0.00143	0.00096
	0.300	...	0.0121	...	...	0.00148	...
	0.500	0.0200	0.0131	0.0175	0.0153	0.00160	0.00108
	0.625	...	0.0133	...	...	0.00164	...
	0.875	...	0.0137	...	...	0.00168	...
	1.000	0.0210	0.0138	0.0185	...	0.00169	0.00114
	1.375	...	...	...	...	0.00171	...
	1.500	...	0.0140	...	...	0.00173	...
	1.750	...	0.0141	...	...	0.00178	0.00116
	1.875	0.0216	...	0.0189	...	...	...
	2.000	...	0.0142	...	...	...	...

However, a slight general tendency was noted that when the value of c was chosen so as to fit test results for small specimens, the values of k' determined for the larger specimens were found to be slightly too large. To correct this tendency, at least partially, advantage was taken of the probable slight minor tendency to weaken small specimens on account of the proportionally larger part of the area occupied by a single grain (5) and the following formula was next tried,

$$\rho' = c\left(1 - \frac{S_y}{S_u}\right)^3 \times \left(1 - \frac{q}{d}\right)$$

where:

d = the diameter of the specimen (in inches),

S_y = the yield strength of the metal,

S_u = the tensile strength of the material (sometimes called the "ultimate" strength), and

c, q = constants.

By the process of trial and error, the values of c and q are taken as 0.2 in. and 0.05 in., respectively, on the basis of giving quite satisfactory agreement between computed values of k' and values of k' directly determined from fatigue test results, so that the following formula is proposed for the value of ρ' for steel. In this formula ρ' and d are both expressed in inches.

$$\rho' = 0.2(1 - S_y/S_u)^3 \times (1 - 0.05/d) \quad (6)$$

In Fig. 3 is shown the method of determining the value of k' by the use of the Neuber reduction diagram, and two illustrative problems are solved.

In Table IV are listed the values computed by the use of Eq. 6. In Table V are listed the values of k', the strength-reduction factor, computed by the use of the Neuber diagrams and the values of ρ' given in Table IV, and also the value of k' given by actual fatigue test results for different size specimens of the steels tested. It will be noted that the maximum deviations of computed values of k' from the values of k' given directly by tests are +6.7 and −8.2 per cent, and the average deviation (disregarding sign) is 2.92 per cent. This result indicates that the method of determining notch effect for various size specimens of steel gives fairly reliable results for round steel parts from 0.125 to 1.875 in. in diameter.

TEST RESULTS FOR S.A.E. 1035 BRIGHT ANNEALED STEEL

To determine whether residual stresses were a main cause of size effect, specimens of S.A.E. 1035 steel 0.125, 0.250, and 0.500 in. in diameter were machined and polished and then bright annealed *in vacuo*, as is described in detail in the Third Progress Report on Size Effect (**1**). Both unnotched and notched specimens were thus treated. Then the specimens were subjected to fatigue tests without further machining or polishing. It was assumed that the thorough anneal would remove any residual stresses, and that if residual stresses were a major cause of size effect, that fact would be shown by a diminution of size effect in the tests of the annealed specimens. For the unnotched specimens no definite difference in size effect was noted for the annealed specimens. The check between predicted endurance limits and endurance limits obtained directly from test results is not noticeably different from the check for specimens which have not been annealed, as may be seen from Table III.

As was expected, both the unnotched specimens and the notched specimens of the annealed steel showed lower fatigue strength than did the specimens tested in the "as rolled" condition. The notch sensitivity of the annealed steel was found to be distinctly higher (value of ρ' lower) than that for the "as rolled" specimens. The strength-reduction factor (by test) for the annealed specimens averaged 1.81, while for the "as rolled" specimens its average value was 1.63. Since the appearance of the Third Progress Report, tests have been made of 0.250-in. fatigue specimens of bright annealed S.A.E. 1035 steel which have been notched and polished *after* annealing. These specimens showed a fairly good check for notch sensitivity with the other fatigue specimens tested, and the values for bright annealed S.A.E. 1035 steel shown in Table V are the values for these specimens notched and polished *after* annealing.

TABLE V.—CHECK OF COMPUTED STRENGTH-REDUCTION FACTOR (k') WITH STRENGTH-REDUCTION FACTOR DETERMINED DIRECTLY BY FATIGUE TESTS.

The Neuber constant ρ' is computed from the formula, $\rho' = 0.2(1 - S_y/S_u)^3 \times (1 - 0.05/d)$, in which S_y is the yield strength of the metal, S_u the tensile strength, and d is the diameter of the specimen.

Then the "theoretical" stress-concentration factor k_t may be determined by the use of the Neuber diagram in Fig. 2, and using the value of ρ' obtained by the above formula, and knowing the angle between the straight sides of the notch (in semicircular notches, and in notches cut "straight in" perpendicular to the surface, the flank angle ω is zero) the computed strength-reduction factor k' may be found by the use of the second Neuber diagram shown on Fig. 3. In both the Neuber diagrams ρ denotes the radius at the bottom of the notch.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Metal	Diameter of Specimen, d, in.	Endurance Limit from Tests, S'_e, psi.		Radius at Root of Notch, ρ, in.	Depth of Notch, t, in.	ρ' from Formula Above, in.	"Theoretical" Stress-Concentration Factor, k_t from Fig. 2	Strength-Reduction Factor from Fig. 3, k'	Strength-Reduction Factor from Tests, (3)/(4)	Deviation of (10) from (9), per cent
		Unnotched	Notched							
S.A.E. 1020 steel, as rolled (series II)	0.125	34 000	22 000	0.01	0.01	0.0133	2.00	1.47	1.54	−4.6
	0.250	32 000	20 000	0.02	0.02	0.0177	2.00	1.51	1.60	−5.6
	0.500	28 900	17 800	0.04	0.04	0.0200	2.00	1.59	1.62	−1.9
	1.000	28 200	17 200	0.08	0.08	0.0210	2.00	1.66	1.67	−0.6
	1.875	28 200	16 000	0.14	0.14	0.0216	2.06	1.76	1.76	0
S.A.E. 1020 steel, strain relieved (series I)	0.125	...	23 000	0.0625	0.0625	0.0087	1.26	1.26	...	...
	0.160	29 000	20 500	0.0200	0.0200	0.0100	1.74	1.43	1.41	+1.4
	0.250	29 000	21 250	0.0625	0.1250	0.0116	1.47	1.33	1.36	−2.2
	0.500	28 000	19 500	0.0625	0.0625	0.0131	1.74	1.51	1.44	+4.9
	0.500	28 000	16 500	0.0200	0.0200	0.0131	2.38	1.76	1.70	+3.5
	1.000	28 000	15 500	0.0200	0.0200	0.0138	2.60	1.87	1.81	+3.3
	1.000	28 000	18 000	0.125	0.125	0.0138	1.74	1.56	1.55	+0.6
	2.000	28 000[a]	15 000	0.0200	0.0200	0.0200	2.80	1.98	1.87	+5.9
	2.000	28 000[a]	17 500	0.2500	0.2500	0.1415	1.74	1.60	1.60	0
S.A.E. 1035 steel, as rolled (series II)	0.125	39 000	27 000	0.01	0.01	0.0117	2.00	1.47	1.44	+2.1
	0.250	39 000	25 000	0.02	0.02	0.0156	2.00	1.55	1.56	−0.6
	0.500	35 000	22 000	0.04	0.04	0.0175	2.00	1.60	1.59	+0.6
	1.000	34 400	19 300	0.08	0.08	0.0185	2.00	1.68	1.78	−5.6
	1.875	34 400	19 300	0.14	0.14	0.0189	2.06	1.78	1.78	0
S.A.E. 1035 steel, bright anneal (series II)[b]	0.250	39 000	23 500	0.02	0.02	0.0136	2.00	1.55	1.66	−7.1
S.A.E. 2345 steel, heat treated (series I)	0.125	70 250	56 500	0.0625	0.0625	0.00107	1.26	1.20	1.24	−3.2
	0.160	70 750	44 500	0.0200	0.0200	0.00123	1.75	1.60	1.59	+0.7
	0.250	66 750	50 000	0.0625	0.1250	0.00143	1.46	1.43	1.34	+6.7
	0.300	70 000	48 250	0.0625	0.0625	0.00148	1.54	1.47	1.45	+1.4
	0.300	70 000	37 000	0.0200	0.0200	0.00148	2.10	1.87	1.89	−1.1
	0.300	70 000	43 500	0.0375	0.0375	0.00148	1.75	1.65	1.61	+2.5
	0.500	66 500	33 550	0.0200	0.0200	0.00160	2.38	2.07	1.99	+3.0
	0.500	66 500	44 500	0.0625	0.0625	0.00160	1.75	1.64	1.59	+3.1
	0.875	64 000	35 000	0.0625	0.0625	0.00169	2.06	1.92	1.83	+4.9
	1.500	66 500	29 500	0.0625	0.1250	0.00173	2.54	2.32	2.25	+3.1
S.A.E. X4130 steel (series II)	0.125	75 400	38 600	0.01	0.01	0.00072	2.00	1.79	1.95	−8.2
	0.250	69 800	37 300	0.02	0.02	0.00096	2.00	1.82	1.87	−2.7
	0.500	65 000	35 800	0.04	0.04	0.00108	2.00	1.86	1.82	+2.2
	1.000	63 600	34 600	0.08	0.08	0.00114	2.00	1.87	1.84	+1.6
	1.750	63 600	34 800	0.14	0.14	0.00116	2.06	1.91	1.83	+4.4

Mean deviation of predicted values of strength-reduction factor k' from test values (disregarding sign) = 2.92 per cent.
Maximum deviations = +6.7 and −8.2 per cent.

[a] Unnotched specimen 1.875 in. in diameter.

[b] These specimens were notched and polished *after* annealing.

The bright annealing did not seem to affect the "size effect" for specimens of S.A.E. 1035 steel, but it did seem to increase the notch sensitivity as compared with that of the "as rolled" specimens. By the action of machining and

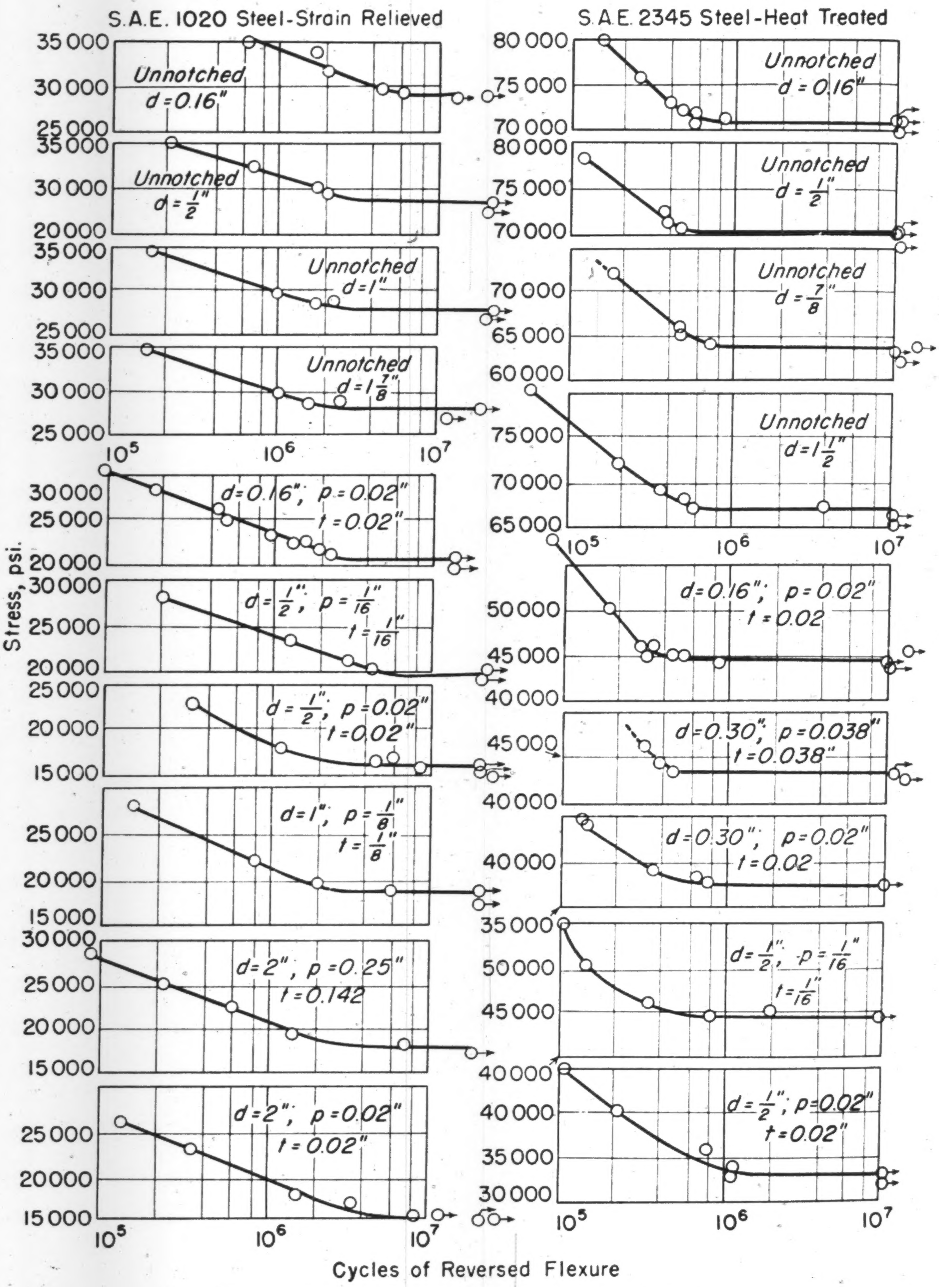

FIG. 4.—*S-N* Diagrams for Fatigue Tests in Series I.

In each *S-N* diagram for notched specimens
d is the diameter of specimen at bottom of the notch,
ρ is the radius of the notch at its root, and
t is the depth of the notch, see Fig. 2.

polishing, the notch sensitivity of the bright annealed steel was lowered to about that of the "as rolled" steel, and the endurance limit of the annealed steel was increased by about 18 per cent.

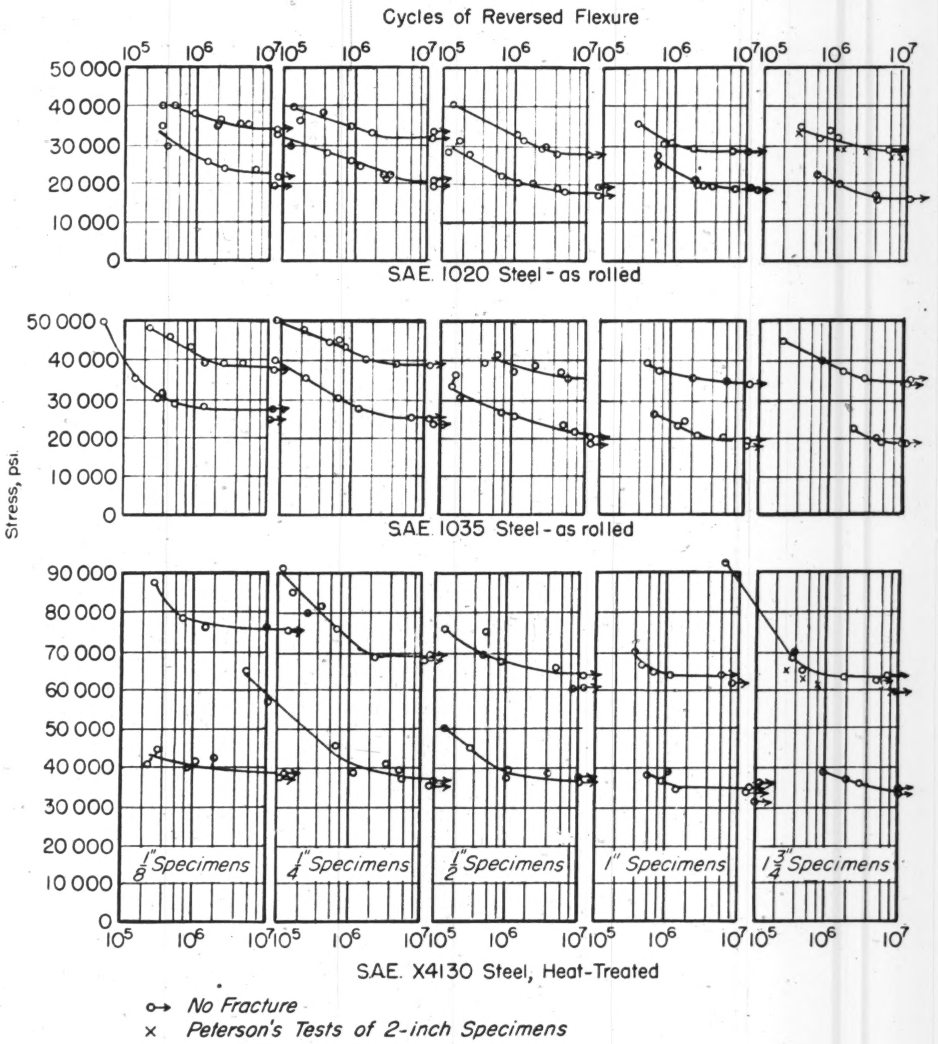

FIG. 5.—S-N Diagrams for Fatigue Tests in Series II.
S-N Diagrams for Bright-Annealed S.A.E. 1035 Steel Shown in Fig. 6.

LIMITATIONS OF THE TEST RESULTS OBTAINED

The tests so far studied are all tests of steel specimens. Whether these methods of estimating size effect and notch sensitivity can be applied to non-ferrous metals awaits actual tests of such metals, and tests of at least one non-ferrous metal are now in progress. The capacity of the largest rotating-cantilever machine available for these tests has limited the maximum critical diameter of specimen to 2 in., and extrapolation of these results to larger sizes is not to be recommended as safe practice, especially in view of reports of larger specimens failing at much lower stresses than those reported in these tests. Whether these results are to be ascribed to "size effect" or to large variations in the strength of the steel throughout the cross-section of these large specimens, or to other causes, is not clear at the present writing. However, the presence of very definite size effect for diameters or thicknesses of steel up to 2 in. has been shown and approximate methods suggested for predicting such size effect and also for predicting notch effect within the limits stated above.

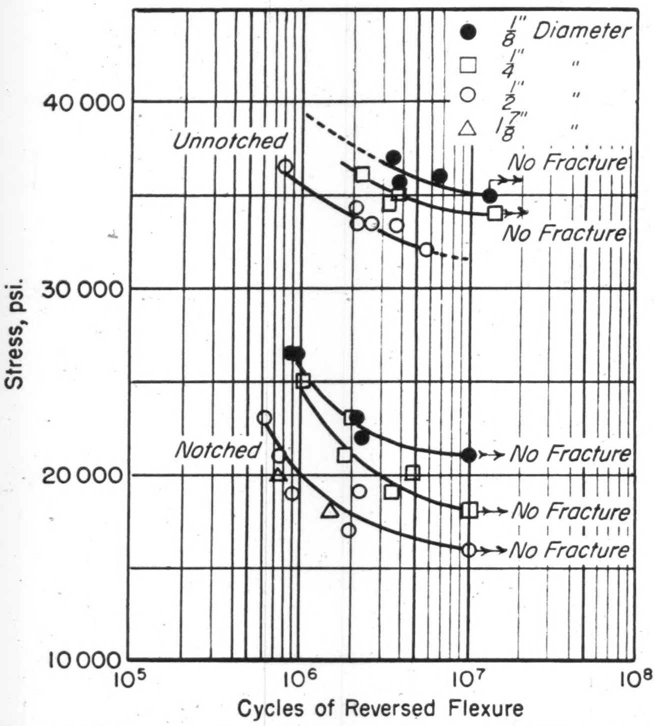

FIG. 6.—*S-N* Diagrams for Fatigue Tests of Bright-Annealed S.A.E. 1035 Steel.

Acknowledgments:

This paper is an outgrowth of the discussion after the oral presentation of the Third Progress Report on Size Effect presented at the 1944 Annual Meeting of the A.S.T.M. in New York. The author wishes to acknowledge valuable suggestions and criticisms by members of the Research Committee on Fatigue of Metals and by visitors to a meeting of the committee where the report came up for consideration, and also suggestions and criticisms which have been received since that meeting. Especial acknowledgment is made to R. E. Peterson of the Westinghouse Research Laboratory.

He wishes to acknowledge the continued assistance of Professor Bruckner of the University of Illinois Metallurgical Laboratories in annealing *in vacuo* specimens of S.A.E. 1035 steel. Both of the series of fatigue tests on which this paper is based were carried on in the Talbot Materials Testing Laboratory at the University of Illinois.

APPENDIX

S - N DIAGRAMS FOR THE FATIGUE TESTS ON WHICH THIS PAPER IS BASED

Figure 4 shows S - N diagrams for most of the fatigue tests in series I, and Figs. 5 and 6 show the S - N diagrams for the fatigue tests except for the tests of bright-annealed S.A.E. 1035 steel specimens which were machined and polished after annealing.

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(3) H. Neuber, "Kerbspannungslehre," Julius Springer, Berlin (1937).

(4) Appendix to the Report of the Research Committee on Fatigue of Metals, *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 143.

(5) H. J. Gough, B. A. Wright, and D. Hanson, "A Test on a Specimen Consisting of Three Crystals under Reversed Torsional Stress," (British) Aeronautical Research Committee, *Reports and Memoranda, No. 1025*, January, 1926.

DISCUSSION

MR. R. E. PETERSON[1] (*by letter*).—Since several analyses have now been made, based on failure involving a distance beneath the surface, of "notch" fatigue data as a function of size, it is probably well to classify the basic assumptions:

1. Basic endurance limit.

(*a*) Consider as a constant for the material, using value for large[2] diameter.

(*b*) Consider as a variable with diameter, using a relation representing rotating-beam values.

(*c*) Consider as a constant S_e (perfect), from which rotating-beam limits are figured as reduced values, variable with diameter, due to inherent "notch" defects.

2. "Theoretical" stress concentration factor, k_t.

(*a*) Neuber value.

(*b*) Photoelastic value multiplied by Neuber ratio of 3-dimensional case to 2-dimensional case.

3. Strength theory.

(*a*) Maximum shear stress (maximum normal stress gives same value in this application).

(*b*) Shear energy.[3]

4. Notch function.

(*a*) Neuber formula

$$k_n = 1 + \frac{k_t - 1}{1 + \sqrt{\rho'/r}}$$

where

k_n = fatigue strength reduction factor due to notch,

ρ' = failure depth, and

r = notch radius.

(*b*) Linear function of constant depth

$$k_n = k_t' \, (1 - C\rho'/r)$$

where C = stress gradient constant (use 3 for notches and fillets).

(*c*) Same as (*b*) but modified so that

$$k_n = 1 \text{ when } r = 0$$

$$k_n = k_t' \left[1 - \frac{1}{r/C\rho' + k_t'/(k_t' - 1)} \right]$$

5. Failure distance beneath surface.

(*a*) Constant for a given material.

(*b*) Variable with diameter.

Analyses made may be tabulated as follows:

Assumptions	Reference	Curve Designation
1(*b*), 2(*a*), 3(*a*), 4(*a*), 5(*b*) ..	Present paper by Moore	A
1(*c*), 2(*a*), 3(*a*), 4(*a*), 5(*a*) ..	Morkovin and Moore[4]	B
1(*a*), 2(*b*), 3(*b*), 4(*b*), 5(*a*) ..	Peterson[5]	
1(*a*), 2(*a*), 3(*b*), 4(*c*), 5(*a*) ..	Peterson[6]	C
1(*a*), 2(*a*), 3(*b*), 4(*a*), 5(*a*) ..		D

While the number of possible combinations of the above assumptions is large, the situation is not as complicated as it might seem, since some of the choices have been found to make but little difference, such as 2(*a*) and 2(*b*).

All analyses make use of a constant failure depth beneath the surface for a

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[1] Manager, Mechanics Dept., Westinghouse Electric Corp., Research Labs., East Pittsburgh, Pa.

[2] Two-in. diameter value has been used where available. In many cases there is not much difference between ½-in. and 2-in. diameter limits. Strictly speaking, to obtain a material constant an axial test (Haigh type), free from gradient, should be used.

[3] This theory may be conveniently introduced by using $k_t' = mk_t$ where $m = 0.91$ (approx.) for notches and fillets. (See footnote 5)

[4] D. Morkovin and H. F. Moore, "Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 137 (1944).

[5] R. E. Peterson, "Application of Stress Concentration Factors in Design," Experimental Stress Analysis, Vol. I, p. 118 (1943).

[6] R. E. Peterson, "Relation Between Life Testing and Conventional Tests of Materials," ASTM BULLETIN, No. 133, March, 1945, p. 9.

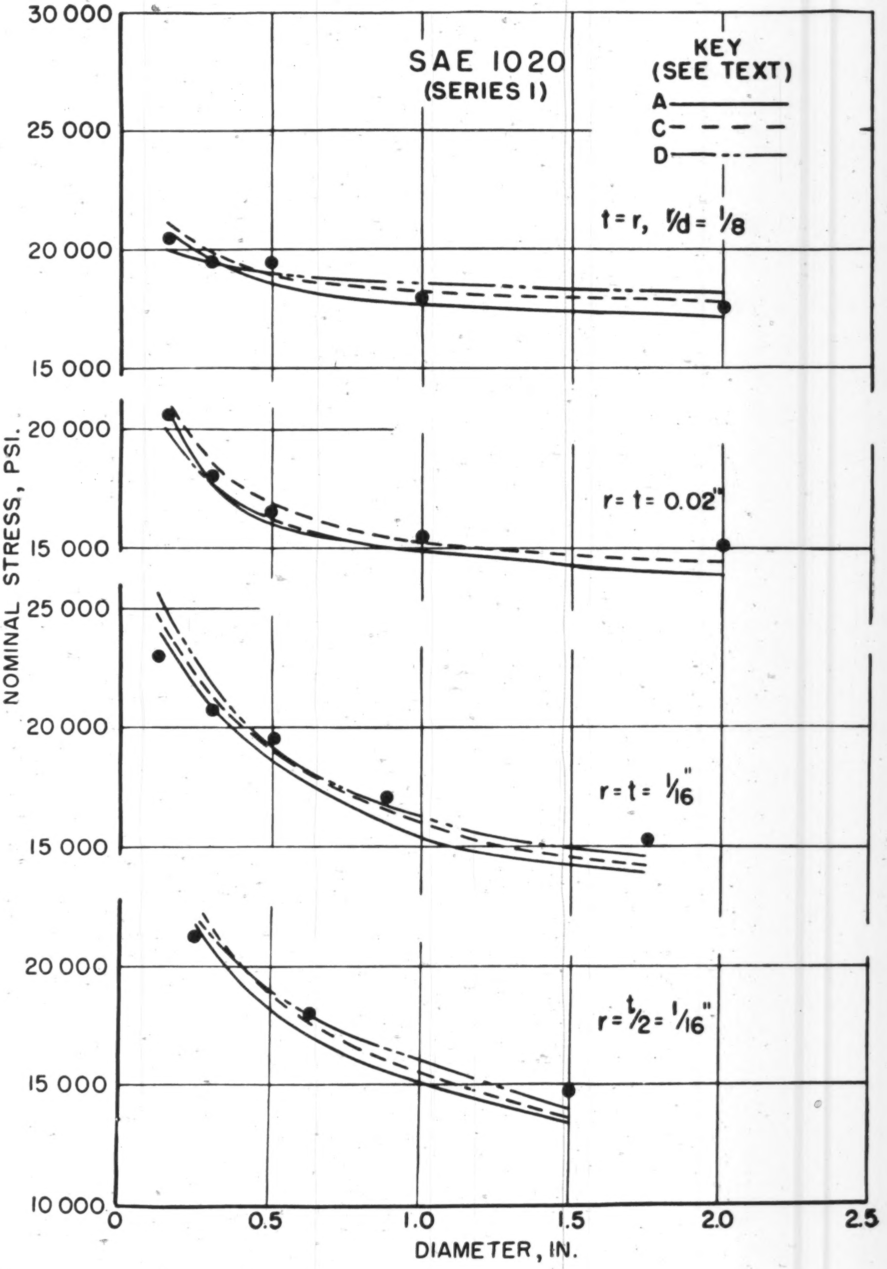
SAE 1020
(SERIES 1)
KEY
(SEE TEXT)
A
C
D
t = r, r/d = 1/8
r = t = 0.02"
r = t = 1/16"
r = t/2 = 1/16"
NOMINAL STRESS, PSI.
30 000
25 000
20 000
15 000
10 000
0
0.5
1.0
1.5
2.0
2.5
DIAMETER, IN.

Fig. 1.

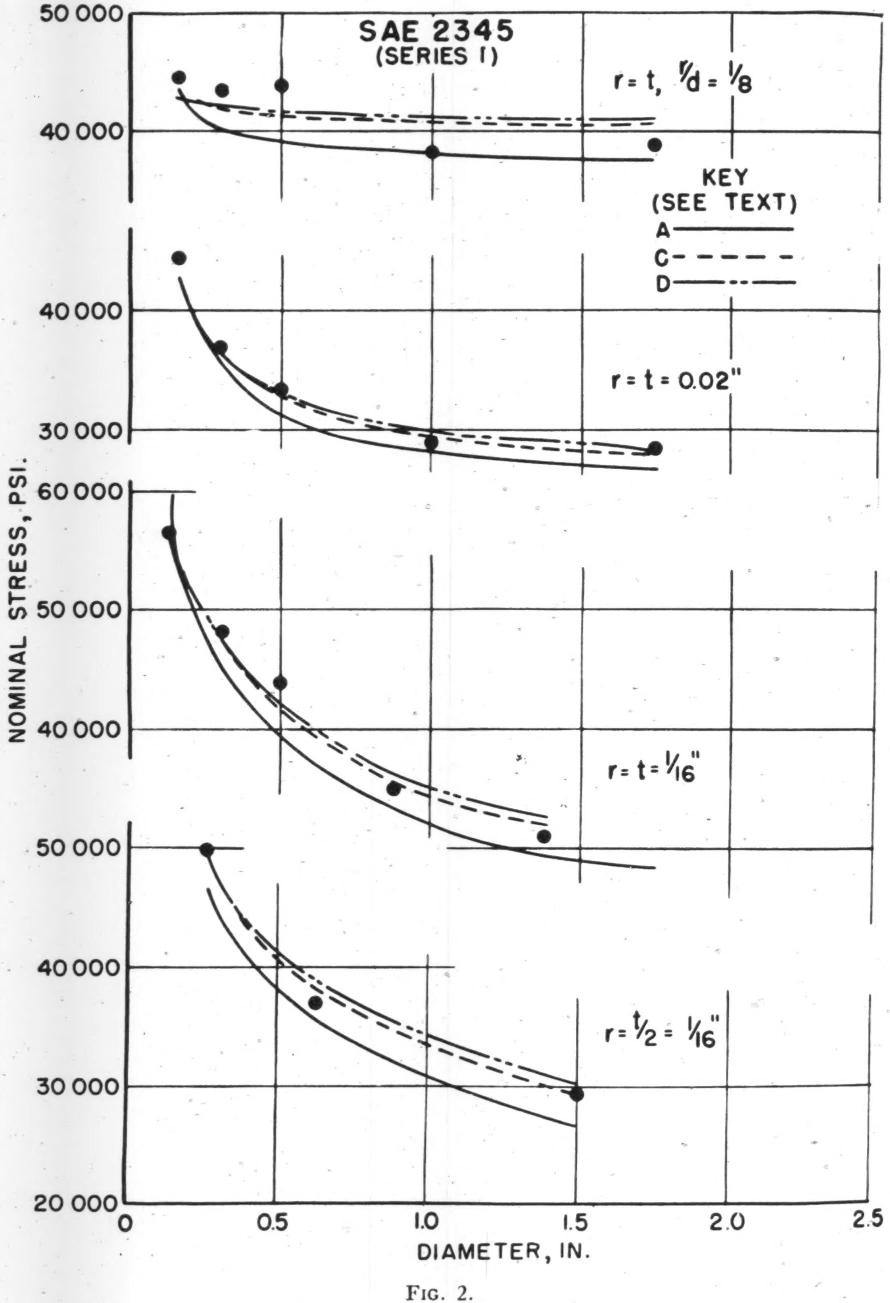
SAE 2345
(SERIES I)
r = t, r/d = 1/8
KEY
(SEE TEXT)
A
C
D
r = t = 0.02"
r = t = 1/16"
r = t/2 = 1/16"
NOMINAL STRESS, PSI.
50 000
40 000
40 000
30 000
60 000
50 000
40 000
50 000
40 000
30 000
20 000
0
0.5
1.0
1.5
2.0
2.5
DIAMETER, IN.

FIG. 2.

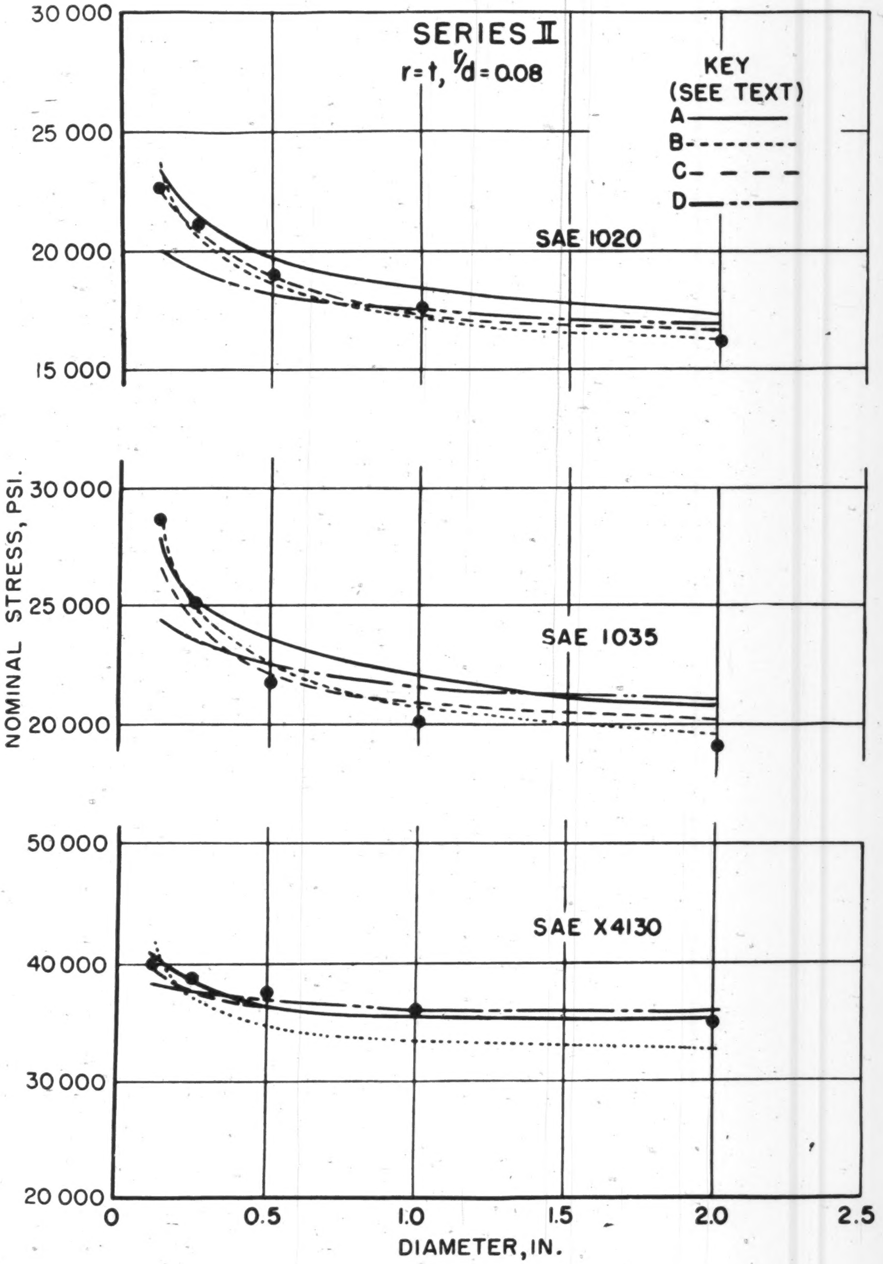
SERIES II
r = t, r/d = 0.08
KEY
(SEE TEXT)
A
B
C
D
SAE 1020
SAE 1035
SAE X4130
NOMINAL STRESS, PSI.
30 000
25 000
20 000
15 000
30 000
25 000
20 000
50 000
40 000
30 000
20 000
0
0.5
1.0
1.5
2.0
2.5
DIAMETER, IN.

FIG. 3.

given material, although in the present paper Moore introduces a multiplier[7] $(1 - 0.05/d)$ to obtain better agreement with the data. Although an assumption of constant depth may give a reasonable interpretation for a limited amount of data, it is by no means established that this is a fundamental fact. If the cold working due to machining is of importance, it could in certain cases result in considerable variation.

It is the writer's opinion that we should not look at the analyses herein discussed as means of establishing fundamentals, but rather as means of providing a designer with a simple approximate method of taking account of notches in figuring the strength of machine parts where repeated stresses are involved. With this in mind, it is of interest to examine the accompanying Figs. 1 to 3. We see that various combinations of assumptions (curves A, B, C, D) can all be made to fit the data reasonably well. For the present purpose, method B could be eliminated as being too complicated, although the ideas may be of scientific interest.

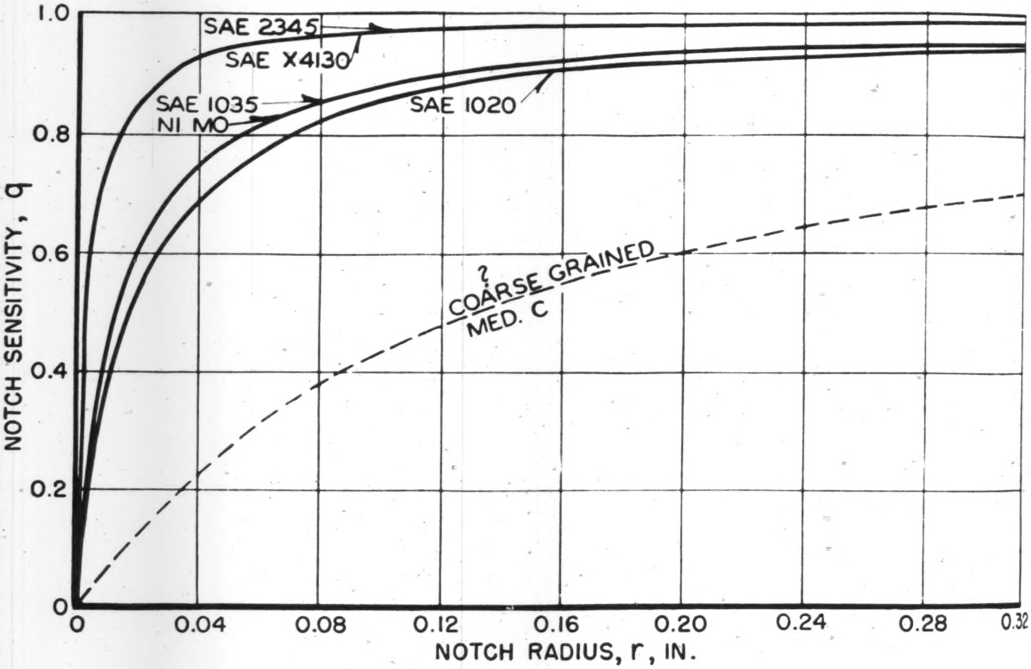

FIG. 4.—Average Notch Sensitivity Curves.

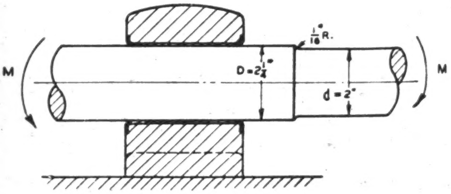

FIG. 5.—Example Used for Fatigue Problem.

From the standpoint of convenience for design, a method described by the author in an earlier paper[5] and illustrated by the accompanying Fig. 4 may be of value. The method may be illustrated by the accompanying Fig. 5 as follows:

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[7] If this multiplier is used in making charts, it should be noted that it becomes negative below a diameter of 0.05 in.

The critical section is at the fillet where $k'_t = 1.85$ (Fig. 13 of footnote reference 6). The material is S.A.E. 1035 steel normalized with an endurance limit for 2-in. diameter of 34,000 psi. (If only the value at 0.273 in. is available, the expected value at 2-in. diameter would be approximately 5 per cent lower using Moore's average results.) The "notch sensitivity" value, q, is 0.82 from Fig. 4. The maximum nominal bending stress which the shaft can carry is then:

$$S_n = \frac{S_e}{1 + q(k'_t - 1)}$$

$$= \frac{34,000}{1 + 0.82(1.85 - 1)} = 20,000 \text{ psi.}$$

The design working stress would include a factor of safety and would, of course, be lower.

Moore's relation between ρ' and S_y/S_u represents a new attempt at further simplification. If cold working is important, such a relationship may not be unreasonable. Using the same data as before, we could then replace the accompanying Fig. 4 by Fig. 6 which would be simpler to use.

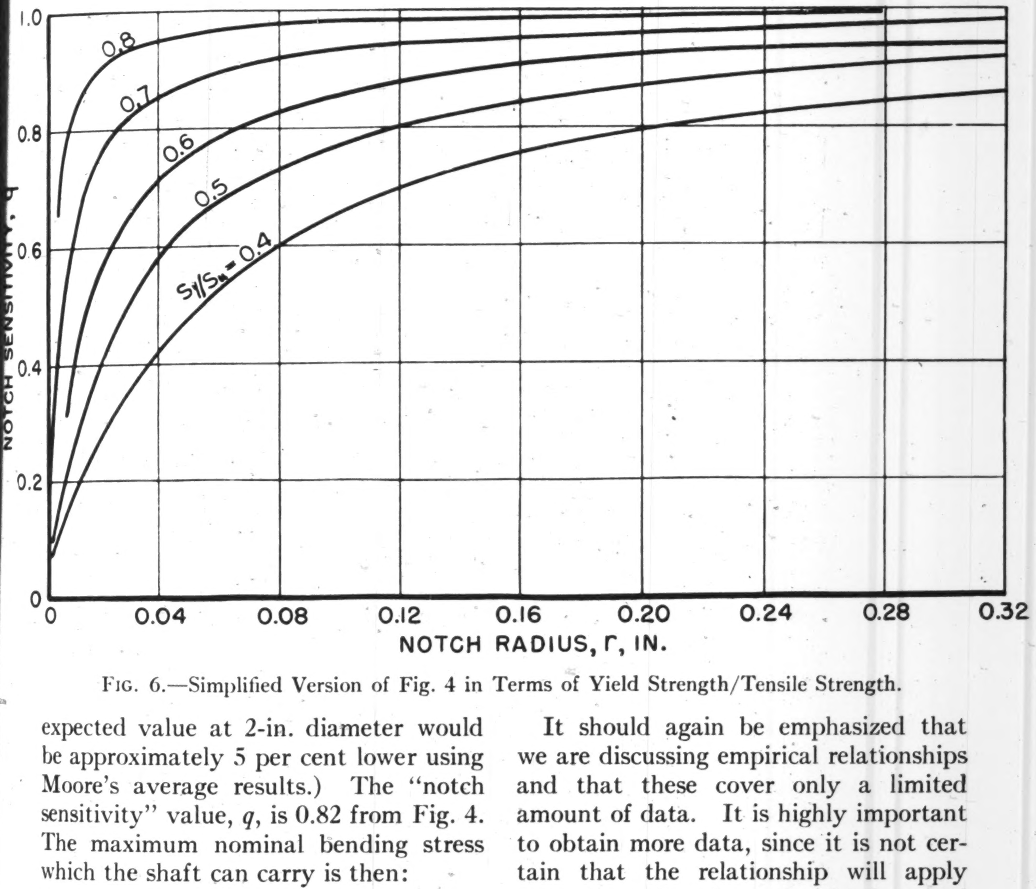

FIG. 6.—Simplified Version of Fig. 4 in Terms of Yield Strength/Tensile Strength.

It should again be emphasized that we are discussing empirical relationships and that these cover only a limited amount of data. It is highly important to obtain more data, since it is not certain that the relationship will apply generally. Questions of a fundamental character, such as those dealing with strength theory, effect of cold working, etc., are difficult to answer with "notch" test data and should be clarified by means of simpler tests.

MR. T. MCLEAN JASPER[8] (*by letter*).—This paper is very timely in that it brings to the attention of engineers and metallurgists one of the most important methods for arriving at the effect of notches in materials built into structures with moving parts. It is believed that the notch type and size can be varied to cover several different shapes which may be met with in machine design. The author has selected a considerable range of material and size of notch. This should set the pace for a considerably extended amount of work in this field.

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[8] Technical and Research Director, General American Transportation Corp., Chicago, Ill.

The method of testing for notch sensitivity is very much more tedious than the single blow impact bending test as represented by the Charpy or Izod methods, but from the point of obtaining results which represent more nearly the conditions met with in service, it is much more to be relied upon than the notch impact bending. It is also believed that although the method is more tedious to apply, it will compensate industry in reducing the confusion and misconception which can surround the less expensive impact bending test.

It is believed that it is very important to calibrate any method of testing with service results if possible. Such calibrations should be in the hands of experienced men as represented by the author.

Since steel is the material used, it is believed that it should be recognized that there is a strong tendency in steel making to improve the quality very materially for the production of aircraft and fast moving machinery. These steels are the ones used most particularly with small factors of safety.

MR. H. F. MOORE (*author's closure, by letter*).—In his interesting and valuable discussion, Mr. Peterson has outlined four procedures for determining endurance limit of large specimens from endurance limit found by test for small specimens, and of determining endurance limit of notched specimens from fatigue tests of un-notched specimens and the mechanical properties of the metal. In this paper and its discussion there are, then, five procedures described by which designers of machine parts may estimate the fatigue strength of such parts. As far as the effect of diameter or thickness of specimen or part ("size effect") is concerned, the differences in resulting fatigue strength as computed by the five procedures are small, although appreciable. Probably any one of the procedures can be used to determine size effect with a good degree of reliability for specimens or parts up to 2-in. thickness or diameter.

The five procedures also include the determination of actual strength-reduction factor k' due to the effect of a notch of given dimensions. The author of the paper was especially interested in the procedure based on Mr. Peterson's article in "Experimental Stress Analysis," Vol. 1, p. 118 (1943) together with the use of Mr. Peterson's Fig. 6 in place of his Fig. 4—a procedure which simplifies computations materially.

In Peterson's Fig. 6 the notch sensitivity factor q is equal to $\frac{k'-1}{k_t-1}$ in which k_t is the theoretical stress-concentration factor and k' is the actual strength-reduction factor. From this it follows that $k' = q\ (k_t - 1) + 1$. The curves in Fig. 6 are plotted on the assumption that the ratio of yield strength to tensile strength of the metal is a significant factor in determining notch-sensitivity. Peterson's factor q then represents the ratio of the actual loss of fatigue strength to the theoretical loss of fatigue strength. Now from the Neuber formula for actual strength-reduction factor

$$k' = 1 + \frac{k_t - 1}{1 + \sqrt{\rho'/\rho}}$$

it follows that Peterson's factor q may be expressed in terms of the Neuber sensitivity factor $\sqrt{\rho'/\rho}$, or

$$q = \frac{1}{1 + \sqrt{\rho'/\rho}}.$$

Using two procedures based on Peterson's reference (2) and on his Fig. 6 and also the procedure used in the paper, a study of the deviations between computed values of k' and the values determined directly from fatigue tests has been made. The results of this study are given in the accompanying Table I. In Table I when the computed strength-reduction factor k' is *greater* than the k' determined directly from fatigue tests, the deviation is listed on the "safe" side. The computation has predicted a strength-reduction factor *larger* than the one found by actual fatigue tests. When computed k' is *smaller* that k' by test, the deviation is listed on the "danger" side.

TABLE I.—DEVIATIONS BETWEEN VALUES OF k' AS COMPUTED AND VALUES DETERMINED DIRECTLY FROM RESULTS OF FATIGUE TESTS.

Procedure	Number of Deviations		Maximum Deviation, per cent		Mean Deviation, per cent		General Mean Deviation, per cent
	on "safe" side	on "danger" side	on "safe" side	on "danger" side	on "safe" side	on "danger" side	
1. Method used in the paper	21	14	7	8	2.7	3.2	2.9
2. Using Peterson's Fig. 6; then determining k' from q; then comparing this k' with the k' determined as the ratio of endurance limit of un-notched specimens to endurance limit of notched specimens of the same size	25	9[a]	12	15	5.8	5.8	5.8
3. Determine q and k' from Peterson's Fig. 6; then compare that computed k' with the k' determined as the ratio of endurance limit of un-notched specimens ¼-in. in diameter to the endurance limit of any given size of notched specimen	18	17	14	10	6.1	5.5	5.8

[a] Data not available for one set of tests when this second procedure is used.

For the first and the second procedure listed in Table I the value of k' by test was determined from the fatigue test results for un-notched and of notched specimens of the same diameter. For the third procedure, the value of k' by test was determined as the ratio of the endurance limit for $\frac{1}{4}$-in. un-notched specimens to the endurance limit for any given size of notched specimen. The stress gradient at the root of a notch is greater than that at the surface of a large notched specimen, and it was felt that the $\frac{1}{4}$-in. un-notched specimen might, in respect to the stress gradient, be more like the notched specimens than the larger un-notched specimens.

From Table I it seems to the author that, while the procedures involving the use of Peterson's Fig. 6 did not show quite so satisfactory agreement between test results and computed results for k' as did the somewhat more elaborate procedure outlined in the paper, yet in view of their simplifying of computations, either one of them might be used as a fairly safe guide in estimating fatigue strength of notched parts. To the author the third procedure seems slightly preferable to the second procedure.

The author agrees heartily with Mr. Peterson's remarks on the empirical nature of the five procedures proposed. In view of the localized beginning of fatigue fracture, and of the irregular and (at present) uncomputable stress distribution between and within the crystalline grains of a metal, it seems highly probable that for some time to come we will have to be content with empirical formulas for fatigue strength. The five procedures seem to the author to offer a reasonably safe and reliable set of methods for the approximate solution of size effect and notch sensitivity problems in the design of structural and machine parts.

After considering the use of Peterson's Fig. 6 for determining notch sensitivity, it occurred to the author that a simplifying diagram for estimating the size effect in un-notched specimens might be useful. The accompanying Fig. 7 shows such a diagram based on the assumption that fatigue fracture acts as if it started slightly below the surface of a specimen. The "nominal" (surface) stress at the surface (S'_e) varies with the diameter of a specimen while at some depth h below the surface there is assumed to be a "basic" stress (S_e) somewhat less than the "nominal" stress and independent of diameter of specimen. Figure 7 shows the computed ratio of S'_e to S_e for a number of values of h. As is shown in Eq. 1 of the paper the value of S_e may be determined if the value of h is known, and from Eq. 3 of the paper the value of h may be determined from two sets of fatigue tests on specimens of two different diameters. For steel specimens it was found that a value of h of 0.008 in. leads to a satisfactory agreement with test results on different size specimens up to 2 in. in diameter. The solution of an illustrative problem will show how Fig. 7 may be used.

Given the nominal endurance limit S'_e of a steel specimen 0.3 in. in diameter as 30,000 psi., and the value of h as 0.008 in. To find the value of S'_e for a specimen of the same steel 0.9 in. in diameter.

From the curve for h equal to 0.008 in. the ratio S'_e/S_e for a specimen 0.3 in. in diameter is 1.054 and for a specimen 0.9 in. in diameter that ratio is 1.02. Then for the 0.9-in. specimen the nominal endurance limit S' is equal to $30{,}000 \times \frac{1.02}{1.054}$ or 29,000 psi.

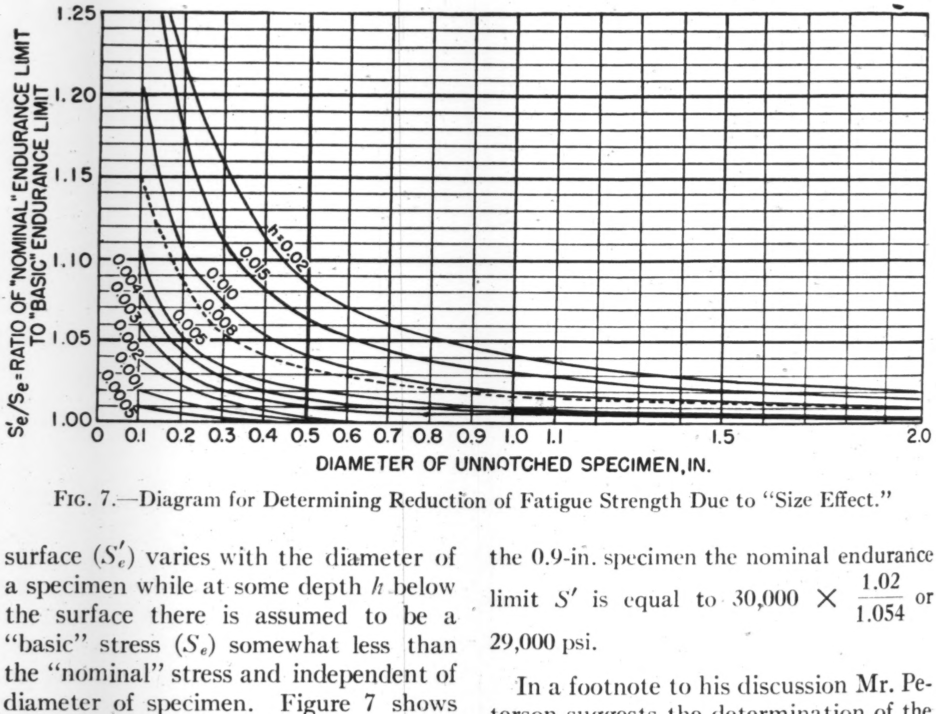

FIG. 7.—Diagram for Determining Reduction of Fatigue Strength Due to "Size Effect."

In a footnote to his discussion Mr. Peterson suggests the determination of the "basic" endurance limit stress directly by the use of the endurance limit given by tests on a direct tension-compression fatigue machine in which the stress gradient across the specimen would, presumably, be zero. A practical difficulty in using this method is the difficulty of actually getting uniform distribution of stress across a tension-compression (push-pull) specimen.

Mr. Peterson does not consider the influence of flank angle of notch on the fatigue strength of a notched specimen. However, this can be done by the use of the Neuber reduction diagram, Fig. 3 of the paper.

An interesting point in Mr. Jasper's discussion of this paper is his reference to the possible use of Charpy or Izod single-blow impact tests to determine notch sensitivity. So far as the author knows, no correlation has ever been shown between the results of notched-bar impact tests and the notch sensitivity of a metal as shown by tests under repeated stress. It seems by no means certain that single-blow tests would cause the same type of structural damage as would fatigue tests. However a study of the relations (if any) between Charpy or Izod test results and results of fatigue tests of notched specimens might yield information of value.

THE EFFECT OF OVERSTRESS IN FATIGUE ON THE ENDURANCE LIFE OF STEEL

By J. B. Kommers[1]

Synopsis

In the past the author has reported tests showing the effects of a limited number of cycles of overstress on the endurance limit of steel. In the present experiments the question to be answered was this: If the endurance life at one overstress is reduced by 50 per cent, say, does that mean that the endurance life at a subsequent higher or lower overstress has also been reduced by 50 per cent?

The results indicate that, when a high overstress has produced a percentage of damage to endurance life, a subsequent lower overstress may show equal damage in some cases and higher damage in others.

On the other hand, when a low overstress is followed by a higher overstress, the indications are that the damage to endurance life is less at the final stress than at the initial. When the initial overstress is low and the number of cycles not too large, the effect of the initial overstress may actually increase the life at the final stress.

The harder, stronger steels seem to be more sensitive to damage than the softer, weaker steels.

These experiments should be looked upon as preliminary explorations in a field that has considerable practical importance. Much more work needs to be done.

In three previous papers the author has discussed the effect of overstressing in fatigue.[2] In those experiments a stress above the endurance limit was applied for a number of cycles less than that necessary to cause failure, and the damage caused by the overstress was measured by the percentage that the new endurance limit had been decreased as compared with the original endurance limit before overstress had been applied.

Since endurance life is an important consideration in many applications of materials subjected to fatigue, it seemed desirable to determine the effect that overstressing produces on endurance life rather than on endurance limit. In these tests the damage caused by an initial overstress is measured by the percentage that the endurance life at a final higher or lower overstress is decreased as compared with the normal life at the final overstress.

Figure 1 shows what is wanted. This is a conventional *S-N* diagram in which the ordinate S is plotted to the natural scale and represents the unit stress to which the specimen is subjected. The abscissa N is plotted to a logarithmic scale and represents the number of cycles required for failure. The ordinate to the horizontal part of the curve represents the value of the endurance limit.

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[1] Professor of Mechanics, University of Wisconsin, Madison, Wis.

[2] J. B. Kommers, "Overstressing and Understressing in Fatigue," *Engineering* (London), Vol. 143, May 28 and June 11, 1937, pp. 620 and 676.

J. B. Kommers, "The Effect of Overstressing and Understressing in Fatigue," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 249 (1938).

J. B. Kommers, "The Effect of Overstressing and Understressing in Fatigue," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 749 (1943).

In Fig. 1 let E be the initial overstress and B the final overstress. Suppose that the specimen is stressed for a number of cycles from E to F, and that EF is 20 per cent of the average normal life EG at the stress E. The ratio of EF to EG will be called cycle ratio and will be expressed in per cent. After the cycles EF have been applied, it is clear that the endurance life at stress E has been decreased or damaged by 20 per cent. Suppose that the specimen is next stressed at the lower stress B and fails at a number of cycles corresponding to the point H. Then HD represents the damage to the average normal life BD that has been caused by the 20 per cent cycle ratio at the stress E, and will be expressed as a percentage of BD. If HD is found to be 20 per cent of the normal life BD, then this result shows that 20 per cent reduction in life at stress E causes an equal damage to life at the lower stress B.

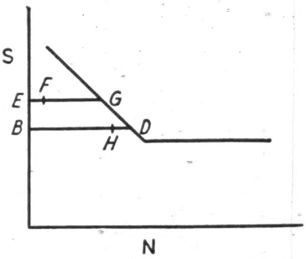

FIG. 1.—Conventional S-N Diagram.

Figure 2 shows a convenient way of plotting results from such overstress tests. The abscissas show the cycle ratios employed at the initial overstress, and the ordinates show the damage determined at the final overstress. If the damage at the final overstress proves to be equal to the damage at the initial overstress (per cent damage equals per cent cycle ratio), then the damage curve will be represented by the 45-deg. line OB. However, if the damage at the final overstress is greater than at the initial stress, the damage curve will lie above the 45-deg. line; and if the damage at the final overstress is less than at the initial overstress, the damage curve will lie below the 45-deg. line.

In this manner experiments were made using the combination of a high initial overstress and a lower final overstress, and also the combination of a low initial overstress and a higher final overstress. The author was especially interested in determining whether damage to endurance life at one overstress caused equal damage to endurance life at a subsequent lower or higher overstress. The results will show that this is true in some cases but not in others.

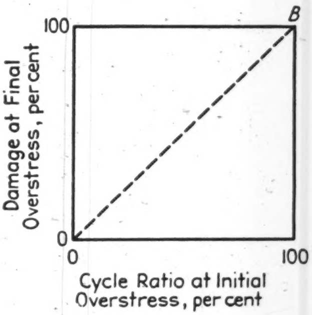
100
B
Damage at Final Overstress, per cent
0
0
100
Cycle Ratio at Initial Overstress, per cent

FIG. 2.—Damage Diagram.

MATERIALS, TESTS, AND TEST SPECIMENS

The two materials investigated were an S.A.E. 1020 steel and a low-alloy high-strength steel, which is called steel B. The chemical composition is shown in Table I, and some of the mechanical properties in Table II.

The S.A.E. 1020 steel was chosen for these tests as an example of a commonly used carbon steel, and steel B was chosen because a supply of it was available and considerable work had been done in determining its mechanical properties. The 1020 steel was received in the form of $\frac{1}{2}$-in. round bars, and steel B as $\frac{3}{4}$-in. round bars. Both steels were tested as received.

The fatigue tests were carried out on R. R. Moore fatigue machines, which subject the rotating-beam specimens to completely reversed bending stresses at a rate of 1750 cycles per minute. Figure 3 shows the fatigue specimen employed. Practically all of the fatigue specimens had a minimum diameter of approximately 0.300 in.

TABLE I.—CHEMICAL COMPOSITION OF TEST SPECIMENS.

Material	Carbon, per cent	Manganese, per cent	Phosphorus, per cent	Sulfur, per cent	Copper, per cent
S.A.E. 1020 steel	0.20	0.37	0.010	0.03	....
Steel B	0.30	1.50	0.019	0.025	0.46

TABLE II.—MECHANICAL PROPERTIES.

Material	Tensile Strength, psi.	Yield Point, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent	Endurance Limit, psi.
S.A.E. 1020 steel	58 750	39 020	44.5	66.6	27 900
Steel B	94 500	56 200	31.5	64.1	45 000

The author wishes to acknowledge the work done on the 1020 steel by Norlin J. Roche, and on steel B by Gordon H. Jaehnig. Thanks are due to the Wisconsin Alumni Research Foundation for providing these research apprentices.

This work has been carried on as a research project in the Department of Mechanics, of which M. O. Withey is chairman, and in the College of Engineering, of which F. Ellis Johnson is dean.

FINAL OVERSTRESS LESS THAN INITIAL

When damage caused by overstressing is measured by the percentage that the new endurance limit is below the original endurance limit, the method has the advantage that the new endurance limit can be determined within close limits. On the other hand, when damage is measured by the percentage that endurance life is less than normal life, the experimenter inevitably encounters scatter. By scatter is meant the range shown in cycles for rupture when a series of specimens is tested at the same unit stress.

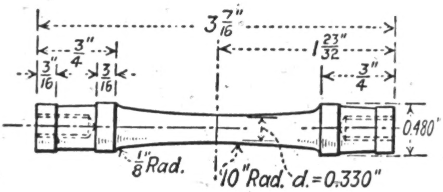

FIG. 3.—Fatigue Specimen.

Since the damage from overstress is to be assessed by results on endurance life, it is evident that scatter will make it necessary to draw average curves for the results. It must be expected that any individual result may deviate widely from such average curves. However, in spite of scatter, it will be found that the results obtained show very definite trends.

Figure 4 shows the results which outline the original *S-N* curve for the S.A.E. 1020 steel. The endurance limit was approximated at 27,900 psi. In the first series of tests the initial overstress was 36,000 psi., which was 29 per cent above the original endurance limit. The average normal life at this stress was 120,000 cycles.

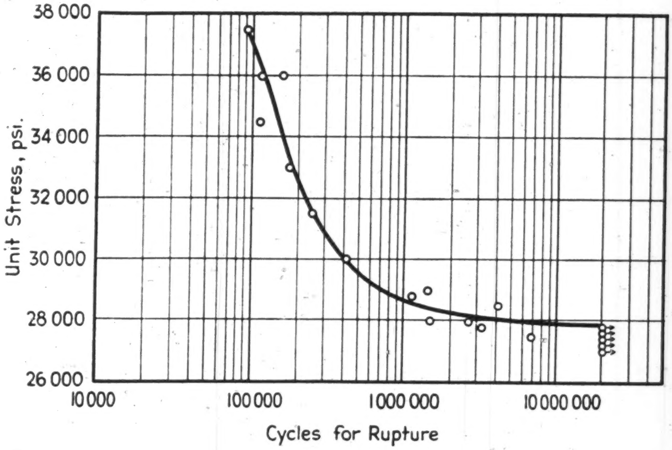

FIG. 4.—Original *S-N* Curve—S.A.E. 1020 Steel.

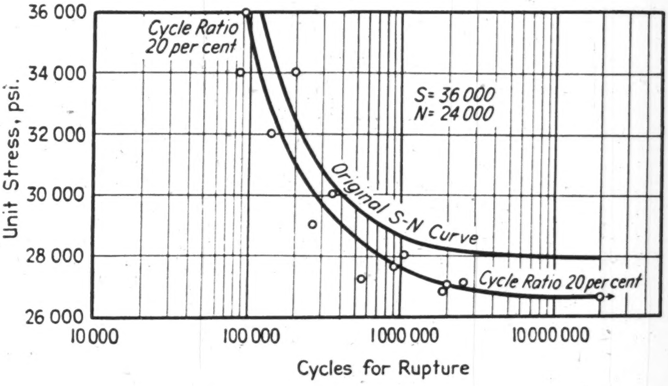

FIG. 5.—*S-N* Curve After 20 per cent Cycle Ratio at 36,000 psi.—S.A.E. 1020 Steel.

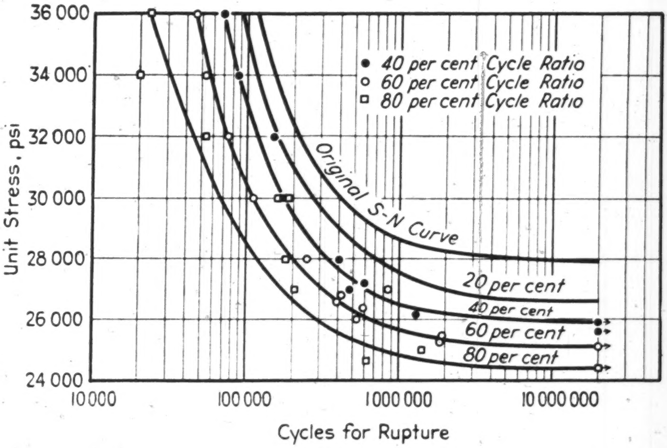

FIG. 6.—Effect of Cycle Ratio at $S = 36{,}000$ psi.—S.A.E. 1020 Steel.

In Fig. 5 the right-hand curve is a reproduction of Fig. 4, but showing no plotted points for the sake of clearness. The plotted points are the results for specimens that were first stressed at 36,000 psi. for a cycle ratio of 20 per cent, which was 20 per cent of 120,000 cycles, or 24,000 cycles. While the plotted points show scatter, as was to be expected, yet it is still possible to draw a fair average curve through the points.

In a similar manner, results were obtained for an initial overstress at 36,000 psi. and cycle ratios of 40, 60, and 80 per cent, corresponding to initial runs of 48,000, 72,000, and 96,000 cycles. The family of curves so obtained is shown in Fig. 6.

Because the material was not as homogeneous as was desirable, thus making the precise position of the *S-N* curves uncertain, the attempt will not be made to draw damage curves from these results. It will be sufficient at present to point out that the curves in the figure are approximately parallel.

In Fig. 6 assume that the various *S-N* curves are exactly parallel to each other from 36,000 psi. down to a stress slightly above the original endurance limit. If this were true for experimental results it would mean that if the damage to endurance life is 20 per cent at 36,000 psi., it is also 20 per cent at any lower unit stress. This follows from the fact that if the logarithms of two numbers (in this case, cycles for rupture) differ from each other by a constant amount, then the numbers themselves form a constant ratio.

However, below the original endurance limit this argument would have no meaning, because, theoretically, the intercept between the original *S-N* curve and that for 20 per cent cycle ratio would be infinite.

Tests to be described later show that in some cases an initial high overstress followed by a lower final overstress produces greater than equal damage. For such cases the family of curves should diverge at the lower stresses instead of being parallel.

Other tests to be described later show that in some cases an initial low overstress followed by a higher final overstress produces less than equal damage. For such cases the family of curves should converge at the higher stresses instead of being parallel.

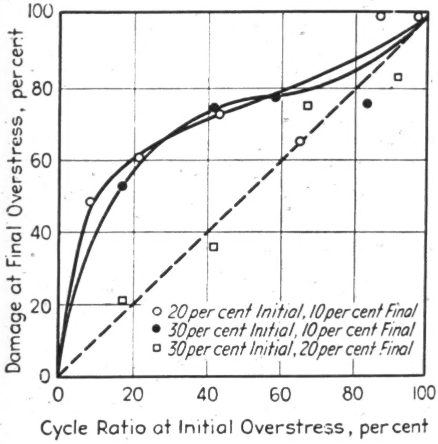

FIG. 7.—Damage Curves for Steel B.

Steel B, shown in Tables I and II was a much stronger steel than the S.A.E. 1020. This steel was tested first, before the idea of a family of curves had been developed. The method used was to test a series of specimens for a given cycle ratio at the same initial and the same final stress and determine the damage in each case. The average damage so obtained gave one point on the damage curve for a given ratio. Using a family of curves as shown in Fig. 6 gives a much wider range of information.

For steel B the following combinations of overstress were used: 30 per cent initial and 10 per cent final, 30 per cent initial and 20 per cent final, and 20 per cent initial and 10 per cent final. The damage curves are shown in Fig. 7. In this figure each plotted point is the average of from two to five results.

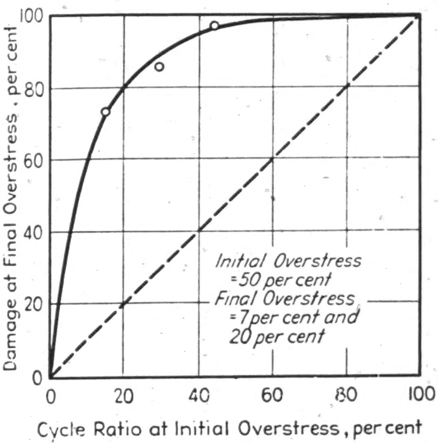

FIG. 8.—Damage Curve for One of Müller-Stock's Steels.

In Fig. 7, for the case of 30 per cent initial and 20 per cent final overstress, the points fall practically on the 45-deg. line, showing equal damage at the two overstresses. For the other two combinations of stress the damage curves lie above the 45-deg. line, indicating that the high initial overstress caused more than equal damage for the lower final stress.

Some results in a paper by Müller-Stock[3] made it possible to obtain some corroborating data. One of his steels was a 0.06 per cent carbon steel of low strength and great ductility. The initial overstress used was 45 per cent above the endurance limit, and at lower overstresses of 27 and 18 per cent, the results fell practically on the 45 deg. damage line, showing equal damage at the high and low stresses. When the final overstress was 9 per cent the damage at this stress was 25 per cent for a cycle ratio of 17 per cent at the initial stress.

A second steel tested by Müller-Stock had a tensile strength of 74,000 psi. and an endurance limit of 42,600 psi. For this steel the initial overstress was 50 per cent, and the damage curves were almost exactly alike when the final overstress was either 7 or 20 per cent. This damage curve is shown in Fig. 8. The initial overstress was admittedly high, and Fig. 8 shows that the damage at the final stress was also high, being 80 per cent when the cycle ratio was 20 per cent at the initial stress.

TABLE III.—DAMAGE TO ENDURANCE LIMIT.

Cycle Ratio, per cent	New Endurance Limit, psi.	Damage to Endurance Limit, per cent
20	26 600	4.7
40	25 900	7.2
60	25 100	10.0
80	24 400	12.5

The results on steel B and this steel of Müller-Stock's suggest that the harder, stronger steels are much more sensitive to damage of endurance life than very ductile low-strength steels. This effect may be related to the difference in notch sensitiveness between hard and soft steels.

In the experiments on the S.A.E. 1020 steel the specimens were subjected to an initial overstress of 29 per cent and cycle ratios of 20, 40, 60, and 80 per cent. Table III shows the new endurance limits after various cycle ratios at 29 per cent overstress. If the curves in Fig. 6 may be considered approximately parallel, so that the cycle ratio is equal to the percentage of damage, then Table III shows that overstress causes a much greater percentage of damage to endurance life than to endurance limit.

It is a curious fact that after this S.A.E. 1020 steel has suffered a life damage of 80 per cent at 36,000 psi., the endurance life will again be indefinitely large if the unit stress is reduced below the new endurance limit of 24,400 psi.

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[3] Müller-Stock, "Der Einflusz dauerend und unterbrochen wirkender, schwingender Überbeanspruchung auf die Entwicklung des Dauerbruchs," Technische Hochschule zu Braunschweig (1937).

The above results show that overstress has a much more serious effect on endurance life than on endurance limit. In a similar way the author's 1943 A.S.T.M. paper[2] has shown that understressing plus subsequent coaxing has a comparatively small percentage effect on endurance limit, but the effect on endurance life may be relatively enormous. In both overstressing and understressing, therefore, the effect on endurance life is much greater than the effect on endurance limit.

If further tests show that overstress produces a family of curves (see Fig. 6) which are practically parallel to the original *S-N* curve, it will be comparatively easy to determine such a set of curves without making all the tests that the author had to make to determine Fig. 6. Suppose that such a family of curves was desired for an initial overstress of 30 per cent above the original endurance limit. If the curves wanted are to be at cycle ratios of 20, 40, 60, and 80 per cent, it would be necessary only to determine the new endurance limits for the various cycle ratios at an overstress of 30 per cent. Knowing the new endurance limits for the four cycle ratios, the separate curves could be drawn approximately parallel to the original *S-N* curve. The new curves would start at the initial stress and at a number of cycles corresponding to the four cycle ratios, and would coincide at the bottom with the new endurance limit for each cycle ratio. Such a technique would make possible the saving of considerable time and labor.

FINAL OVERSTRESS HIGHER THAN INITIAL

The tests previously described involved a final overstress that was lower than the initial overstress. The tests now to be described involved a final overstress that was higher than the initial overstress.

These tests on the S.A.E. 1020 steel developed a behavior that had not been observed before. After the specimen had been subjected to a low stress of 5 per cent above the original endurance limit, and the stress then increased to a higher stress, it was found that many specimens failed by static bending instead of by fatigue. Deflection tests showed that the initial cycles had not changed the stiffness, and the conclusion was reached that the tapered sockets in which the ends of the specimens fit had become worn, thus allowing a slight amount of movement. When this was corrected, no further difficulty was encountered.

TABLE IV.—RESULTS FOR DRAWING DAMAGE CURVES—S.A.E. 1020 STEEL.

Final Overstress	Initial Over-stress	Cycle Ratio at Initial Over-stress, per cent	Final *N*	Normal *N*	Damage, cycles	Damage, per cent
1.10	1.05	20	688 700	320.000	—368 700	—115
1.10	1.05	40	591 000	320 000	−271 000	−84.7
1.10	1.05	60	353 900	320 000	−33 900	−10.6
1.10	1.05	80	375 600	320 000	−55 600	−17.5
1.15	1.05	20	362 900	220 000	−142 900	−64.9
1.15	1.05	40	298 200	220 000	−78 200	−35.5
1.15	1.05	60	258 700	220 000	−38 700	−17.6
1.15	1.05	80	193 600	220 000	26 400	12.0
1.20	1.05	20	211 000	168 000	−43 000	−25.6
1.20	1.05	40	262 200	168 000	−94 200	−56.1
1.20	1.05	60	163 800	168 000	4 200	2.5
1.20	1.05	80	71 500	168 000	96 500	57.4
1.25	1.05	20	143 000	140 000	−3 000	−2.1
1.25	1.05	40	115 400	140 000	24 600	17.6
1.25	1.05	60	34 800	140 000	105 200	75.1
1.25	1.05	80	66 100	140 000	73 900	52.8
1.25	1.10	20	150 700	140 000	—10 700	—7.6
1.25	1.10	40	145 500	140 000	−5 500	−3.9
1.25	1.10	60	114 500	140 000	25 500	18.2
1.25	1.10	80	124 500	140 000	15 500	11.1

NOTE.—Negative damage means an increase of endurance life.

Table IV gives the results from which the damage curves for the S.A.E. 1020 steel were drawn. Figure 9 shows the results obtained when the initial overstress was 5 per cent above the original endurance limit, and the final overstress was 10, 15, 20, and 25 per cent.

Because of the difficulty encountered by failure of specimens in static bending, the points plotted in Fig. 9 are the averages of only one to three results.

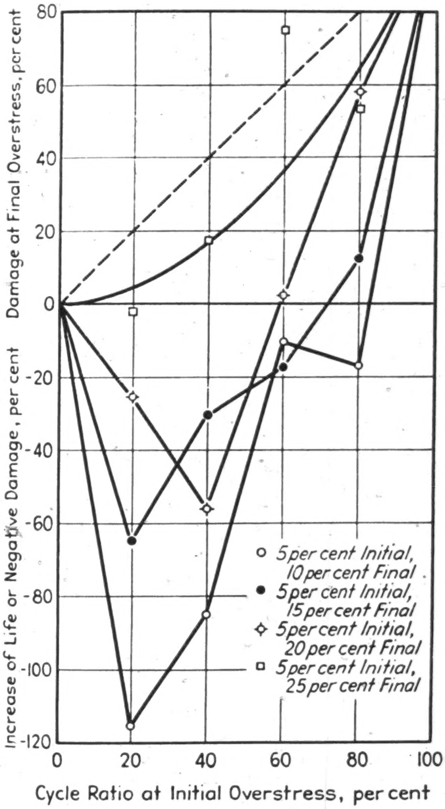

FIG. 9.—Damage Curves for S.A.E. 1020 Steel.

It was found that as more results were averaged for any plotted point, the damage curves tended to lose their jagged shape and become more smooth. If more results had been averaged for each point, the numerical values of the plotted points would be somewhat different, but the trend of the curves would be as shown.

Figure 9 shows that after a low overstress of 5 per cent and a cycle ratio of 20 per cent the endurance life at 10 per cent overstress may be increased by more than 100 per cent. For this combination of overstresses, there is an increase of endurance life even after a cycle ratio of 80 per cent. As the difference between the two overstresses increases the increase of endurance life diminishes, and in the case of 5 per cent initial and 25 per cent final overstress, the damage curve is approaching the 45-deg. line of equal damage.

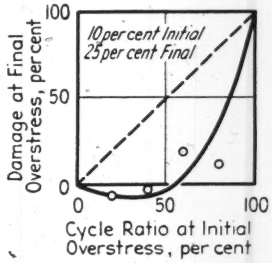

FIG. 10.—Damage Curve for S.A.E. 1020 Steel

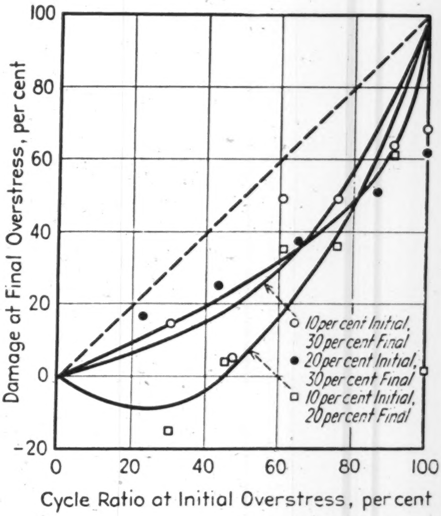

FIG. 11.—Damage Curves for Steel B.

In Fig. 10 the initial overstress was 10 per cent instead of 5, and the final overstress was 25 per cent. The damage curve lies somewhat lower than the uppermost curve in Fig. 9.

Three damage curves for steel B are shown in Fig. 11. Each plotted point represents, in general, the average of two results, but in a number of cases from three to five results were used. For the case of 10 per cent initial and 20 per cent final overstress there is some increase of endurance life, but for the other two curves the plotted points all lie above the line of zero damage.

Figure 12 shows the case of 10 per cent initial and 20 per cent final overstress for specimens that had a ground surface instead of a polished surface. The damage curve is very similar to the corresponding one in Fig. 11.

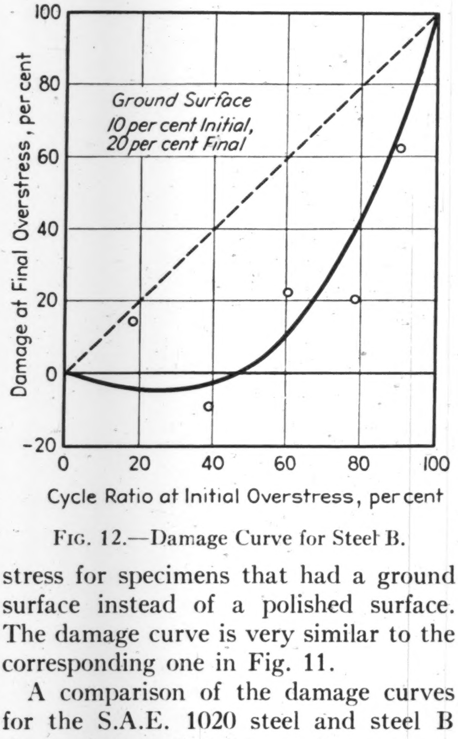

FIG. 12.—Damage Curve for Steel B.

A comparison of the damage curves for the S.A.E. 1020 steel and steel B shows that steel B has smaller percentages of increased life than the 1020 steel. Evidently the stronger steel is more sensitive to damage.

Figures 9 to 12 show that when a low initial overstress is followed by a higher final stress, the effect on the two steels for some ranges of cycle ratio is to strengthen the material so that the endurance life at the higher stress is greater than the normal life at that stress. This is shown by that portion of the damage curve that lies below the line of zero damage. For the larger cycle ratios and the higher initial stresses, there may be no actual increase of endurance life, but the damage at the final higher stress is less than the damage at the initial stress. This is shown by the fact that the damage curves all lie below the 45-deg. line of equal damage. If this phenomenon is found to be generally true for all steels, it may be assumed that when a steel has had, say, 40 per cent of its endurance life used up at a low overstress, it will have left at least 60 per cent of its normal life at any higher stress. This may be contrasted with the case of a high overstress followed by a lower stress, in which 40 per cent damage at the high stress might mean 80 per cent damage at the low stress, or a remaining life of only 20 per cent.

For the combination of low initial overstress and high final stress, Müller-Stock shows five damage curves for his 0.06 per cent carbon steel. In four out of five cases a portion of the curve falls below the line of zero damage, indicating increased endurance life. He believes that the fifth curve would also have shown increased life except for scatter.

CONCLUSIONS

1. A high initial overstress for a given cycle ratio followed by a lower overstress may, in some cases, show equal damage to endurance life at the high and low stresses. In other cases the higher stress may cause a greater percentage of damage at the lower stress.

2. A low initial overstress for a given cycle ratio followed by a higher overstress will generally show that the percentage of damage to endurance life at

the lower stress has caused a smaller percentage of damage to endurance life at the higher stress.

3. Low initial overstress, for small initial stresses and the lower cycle ratios, may produce actual increase of the normal endurance life at a subsequent higher stress.

4. For both the combinations of overstress mentioned under (1) and (2) above, it appears that the steels of higher tensile strength and lower ductility are more sensitive to damage than the weaker steels with greater ductility.

5. If these facts are found to be generally true for all steels, it may be assumed that a low initial overstress will not cause more than equal damage to endurance life at a subsequent higher stress. On the other hand, a high initial overstress may cause much more than equal damage to endurance life at a subsequent lower stress.

6. The tentative conclusions expressed above indicate certain trends. Further work is planned so that more complete information will be available.

DISCUSSION

MESSRS. H. J. GROVER[1] AND L. R. JACKSON[1] (*by letter*).—Mr. Kommers' paper is an interesting and valuable contribution to information on fatigue properties of importance in service conditions.

One of the results quoted is rather surprising. Figure 9 shows measured percentage change in life, at each of four test levels, due to previous loading at a low initial stress level. As the difference between the initial level and the final level decreases, the increase of endurance life gets larger, so that the plotted values depart further from the 45-deg. line representing the case where measured percentage damage and cycle ratio are equal. Yet, for the limiting case where the difference between the two levels is zero, the percentage damage must equal the cycle ratio. The effect of varying the difference between the stress levels is not very definite in the other instances quoted (Figs. 7, 8, and 11), but in no case does there seem to be a systematic approach of measured damage to cycle ratio as the final stress level approaches the initial stress level. This unexpected behavior warrants further examination.

Some service conditions (in aircraft, for example) impose a wide range of load magnitudes upon a part. For such cases, the excess damage caused by high loads may be offset by the strengthening from low loads. For such cases, the cycle ratio may afford a very useful approximation to the resultant damage effective at any stress ratio. For example, the data shown for steel B imply that a sample run for 20 per cent of its endurance life at *each* of *three* stress levels (30 per cent overstress, 20 per cent overstress, and 10 per cent overstress) might show a resultant damage, at a final level of 20 per cent overstress, of only *30 per cent* compared to the cumulative cycle ratio of *60 per cent.* If, as may happen in service, the distribution of loads is such that high stresses occur less frequently than low loads (relative to *S-N* curve), the cycle ratio would afford an even more conservative estimation of damage. It would be of considerable interest in some practical applications to have data on the cumulative damage produced by several stress levels.

It is to be hoped that Mr. Kommers' work will stimulate further interest, both in the understanding of basic phenomena involved in behavior of metals under repeated loading and in obtaining useful approximations for estimating the endurance of materials subject to loading at many different stress levels.

MR. J. B. KOMMERS (*author's closure by letter*).—The question discussed in their first paragraph by Messrs. Grover and Jackson is an interesting one. Let me say, first of all, that the type of result shown in Fig. 9 has been found on two different steels, and has also been found in Germany by Müller-Stock. In such experiments I would always expect some inconsistency because of scatter of endurance life, but I believe the trend shown is correct. However, I fully expect to perform many more experiments in order to be certain of the results.

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[1] Battelle Memorial Institute, Columbus, Ohio.

Perhaps French's damage line may offer a clue as to the explanation of such behavior. From this damage line we know that with small cycle ratios and small overstresses there is no damage to endurance limit. The present tests indicate that there may be an actual increase of endurance life. If these low stresses, slightly above the endurance limit, have an effect which strengthens the material for higher stresses, then it would seem reasonable to get results such as shown in Fig. 9. The action would be analogous to that of stressing a virgin material just below the endurance limit, which we know increases the endurance life for higher stresses. The benefit conferred by understressing cannot be found by continuing at the same stress, but is made obvious by testing at a higher stress. In the overstressing case, any benefit to endurance life conferred by the lower overstress cannot be found by continuing at the same stress, but seems to be made apparent by testing at a higher stress.

Furthermore, it should be pointed out that French's damage line, while it shows no damage to endurance limit for small stresses and small cycle ratios, also shows that when a test is continued at a constant stress to failure, there is no change in the end result.

In studying the effect of overstressing, both on endurance limit and on endurance life, I have been making an attempt to find out what changes are going on in the material on its journey to failure. The changes which occur after a partial run to failure usually decrease the endurance limit, but the present tests indicate that they do not always decrease the endurance life.

With respect to the second paragraph of the discussion by Messrs. Grover and Jackson, I will say that I have made no tests in which more than two stress levels of overstressing were employed. After only two stress levels have been more thoroughly examined, it will be interesting and valuable to investigate the case of cumulative damage from a series of stress levels.

A SULFUR PRINT METHOD FOR THE STUDY OF CRACK GROWTH IN THE CORROSION-FATIGUE OF METALS[1]

BY R. C. BRUMFIELD[2]

The author has endeavored to describe a new procedure for studying the corrosion-fatigue of metals in so far as this procedure differs from the practices so widely known through the writings of D. J. McAdam, Jr., and his associates.[3] Although the novel features of the new procedure lie chiefly in the art of making and analysing contact (sulfur) prints, certain modifications have been necessary in the procedure for testing specimens. In describing the equipment and procedure, the author has approximated the chronological order of the experiences of a specimen in being tested and analysed. For purposes of illustration and example, the text has been written around the investigations undertaken by the author in order to prove the method.[1]

DESCRIPTION OF THE FATIGUE MACHINE, THE SPECIMENS AND AUXILIARIES

The corrosion-fatigue machine used by the author was of the rotating-beam type and operated at 1425 rpm. (see Fig. 1). Weights on the loading rack induced a uniform bending moment in the specimen over the working section and as the spindles rotated, the material in the specimen was subjected to a sinusoidal stress variation.

A drawing of the center section is shown in Fig. 2. The spindles rotated in unpacked journal bearings, lubricated by a gear-type oil pump. Drawbars held the specimen into accurately mated tapers and effected an excellent seal against seepage through the spindles. The rotating seal was formed by spring-loaded Bakelite tubing pressing against the ends of the spindle. A sample of the corrosive medium was circulated through the gland with a Downington-Huber "Squeegee" pump. Dashpots were used to reduce vibration and counterweights eliminated the tare.

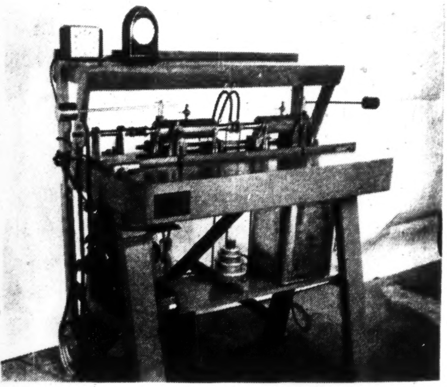

FIG. 1.—The Corrosion-Fatigue Machine

The specimens were of constant diameter (0.300 in.) in the center section and hence the maximum nominal stress amplitude was uniform in the working region. The center section was very carefully polished and the fillets protected from corrosion by a coat of spar varnish with a serrated edge. This protected the specimen from breaks at the fillets and at the edge of the varnish.

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[1] This article summarizes the Francis J. Cole Scholarship Memoirs (1941-1942 and 1942-1943 awards in Mechanical Engineering) which were presented in thesis form entitled "A Method for Recording and Studying Crack Growth in the Corrosion Fatigue of Metals" to the California Institute of Technology in partial fulfillment of the requirements for the degree of Doctor of Philosophy (1943).

[2] Instructor in Mechanical Engineering, California Institute of Technology, Pasadena, Calif.

[3] "Prevention of the Fatigue of Metals," *Battelle Memorial Institute*, Corrosion Fatigue, Appendix 15, Size Effect, Appendix 6, 1941.

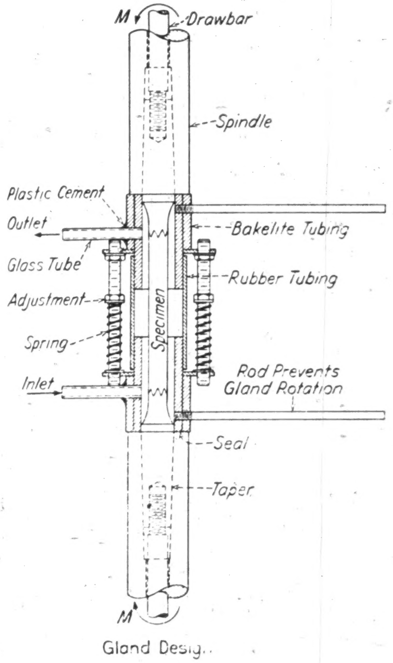
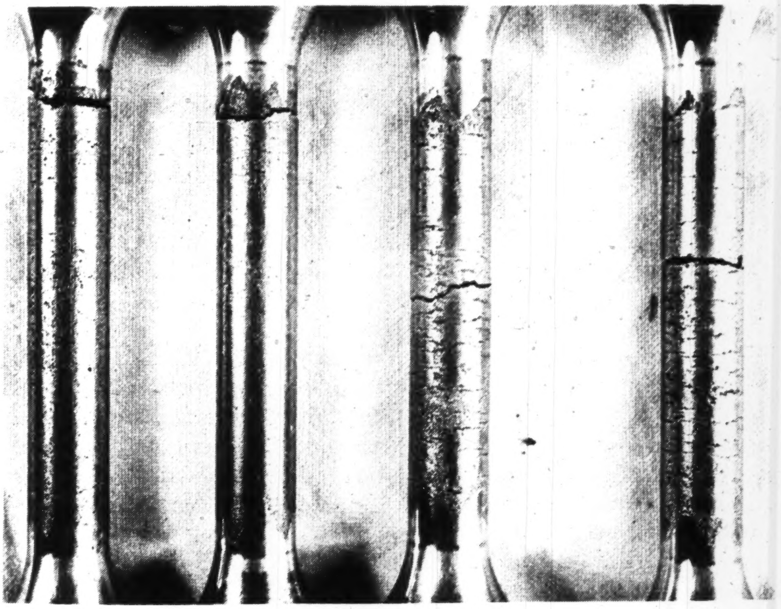

M
Drawbar
Spindle
Plastic Cement
Outlet
Glass Tube
Adjustment
Spring
Inlet
Bakelite Tubing
Rubber Tubing
Specimen
Rod Prevents Gland Rotation
Seal
Taper
M
Gland Desig..

FIG. 2.—Water Gland Design.

The machine was driven with an electric motor through a V-belt, a universal joint and a jack-shaft tilted to allow for specimen deflection. Upon failure of the specimen, a switch automatically disconnected the driving motor and the two electric clocks. Both clocks were excited at 60 cycles, but one was designed for 50 cycle current and gained by 12 min. per hour. The time cycle was thus increased from 12 hr. to 60 hr., eliminating the necessity for attending the machine at intervals of less than 12 hr.

DAMAGING OF THE SPECIMENS

The author damaged twenty S.A.E. ×4130 specimens at four different stress levels for various periods of time in order to obtain a good distribution of data over the important regions on the nominal stress *versus* time at stress plot. Some were run to destruction, others



D-1 D-2 D-3 D-4

FIG. 3.—Specimens Damaged in Air-Saturated Oil-Well Brine. Corrosion Products Removed.

only partially damaged. In any case, the specimens were carefully extracted from the machine, the corrosion products were removed with fine steel wool and photographs taken. Specimens with corrosion-fatigue products removed are shown in Fig. 3. The appearance of corrosion-fatigue fractures is shown in Fig. 4. Note that the failures were due to the interaction and joining of several cracks. This is characteristic of most corrosion-fatigue failures. The sulfur print method was developed for studying and recording corrosion-fatigue damage as manifested in the formation of these cracks.

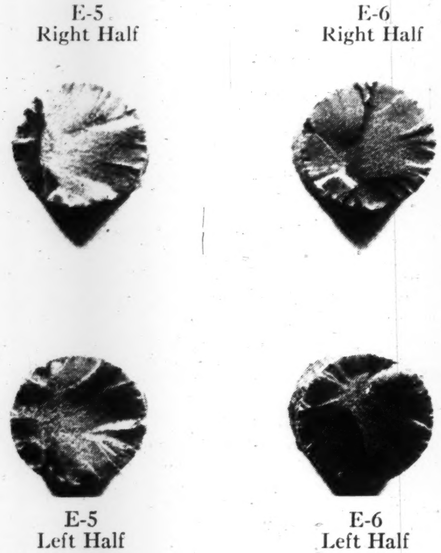

E-5 Right Half
E-6 Right Half
E-5 Left Half
E-6 Left Half

FIG. 4.—End Views of Corrosion-Fatigue Fractures.

PREPARATION OF THE SPECIMENS FOR SULFUR PRINTING

Damaged specimens that had not been broken were cut transversely in two near the middle and at least one half used for making sulfur prints.

The tapered end of the damaged specimen was rigidly fastened into the headstock of a Southbend 9-in. lathe by means of a taper adapter and drawbar and the end was trimmed smooth. A fine cutting tool was then used to remove the metal on the surface down to the bottom of the deepest pits. The new cylindrical surface was then made smooth with No. 320 grit emery cloth. (Each specimen was later cut to successively smaller diameters, in small steps, by the above procedure, a sulfur print being made after each cut).

The diameter of the specimen cut in this way was then measured to ±0.3 mils with a Brown & Sharpe micrometer and recorded. The specimen was then ready for the sulfur printing process.

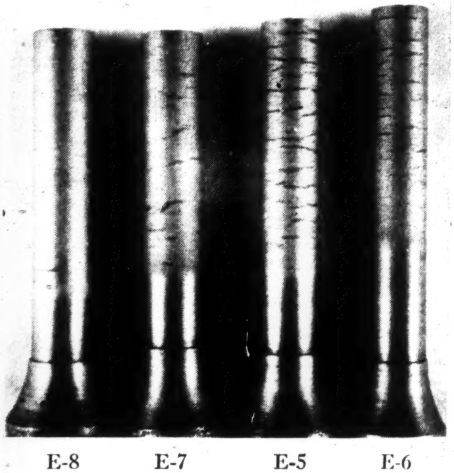


FIG. 5.—Damaged Specimens Cut to a Radial Depth of 7 per cent and Etched to Show Cracks (Time of Damage at 12,500 psi. Increases, left to right).

METHOD FOR MAKING SULFUR PRINTS

Specimens with some of the damaged material removed, as described above, were treated as follows:

(*a*) Washed in alcohol to remove cutting oil and then dried.

(*b*) Soaked in concentrated (Technical) HCl for 30 to 40 min. to open up the cracks smeared over by the cutting tool and emery cloth.

(*c*) Removed from HCl, washed in tap

water, and dried thoroughly with paper towels. The specimens then appeared as shown in Fig. 5.

(*d*) Left soaking in a water solution of Na_2S (1 part of $Na_2S \cdot 9H_2O$ + 2 parts distilled water) for 45 min., or longer, until the author was ready to print them one at a time.

(*e*) A specimen was removed from the Na_2S solution, quickly and thoroughly dried. If a clean surface was not obtained, the specimen was dipped back in the solution and then dried again. (The cleanliness of the surface determines the lightness and uniformity of the crack print background. Light, uniform backgrounds are attractive, but they are not essential to prints used for analysing.)

(*f*) A small piece of sulfur printing paper (prepared as described below) was then carefully wrapped around the specimen to avoid smearing; overlapped, pressed firmly in place, and removed from the specimen surface. If carefully done, a clear and distinct reproduction of the crack pattern was transferred to the printing paper immediately on contact with the steel.

The sulfur print was then marked for identification, fixed in hypo, washed, ferro-typed, and dried. If the first print was not satisfactory, the specimen was dipped back in the Na_2S, dried, and the process repeated.

The type of paper recommended for making sulfur prints is a No. 4 *Azo* or *Velox*, *glossy*, *single weight* photographic printing paper.

The printing paper was cut into small rectangles 1 by $1\frac{1}{2}$ in. These pieces were soaked in tap water for 15 min. or more to soften up the paper and gelatin. The soft paper was then "pre-formed" to help in bending around the small specimen diameters. The pre-forming was done by rolling the paper in the fingers around a small ($\frac{1}{8}$-in. diameter) glass rod.

Just before removing the fatigue specimen from the Na_2S for the purpose of printing, one of these pieces of paper was blotted carefully between paper towels to remove all excess surface moisture. This helped to prevent skidding by giving the printing paper surface a tacky consistency which readily adherred to the dried specimen surface.

Sulfur printing requires a certain amount of skill and care, particularly for the production of prints with light, uniform backgrounds. For analysing, however, such a background is not necessary. The degree of skill required is not different from that necessary to "roll your own" without spilling half of the tobacco.

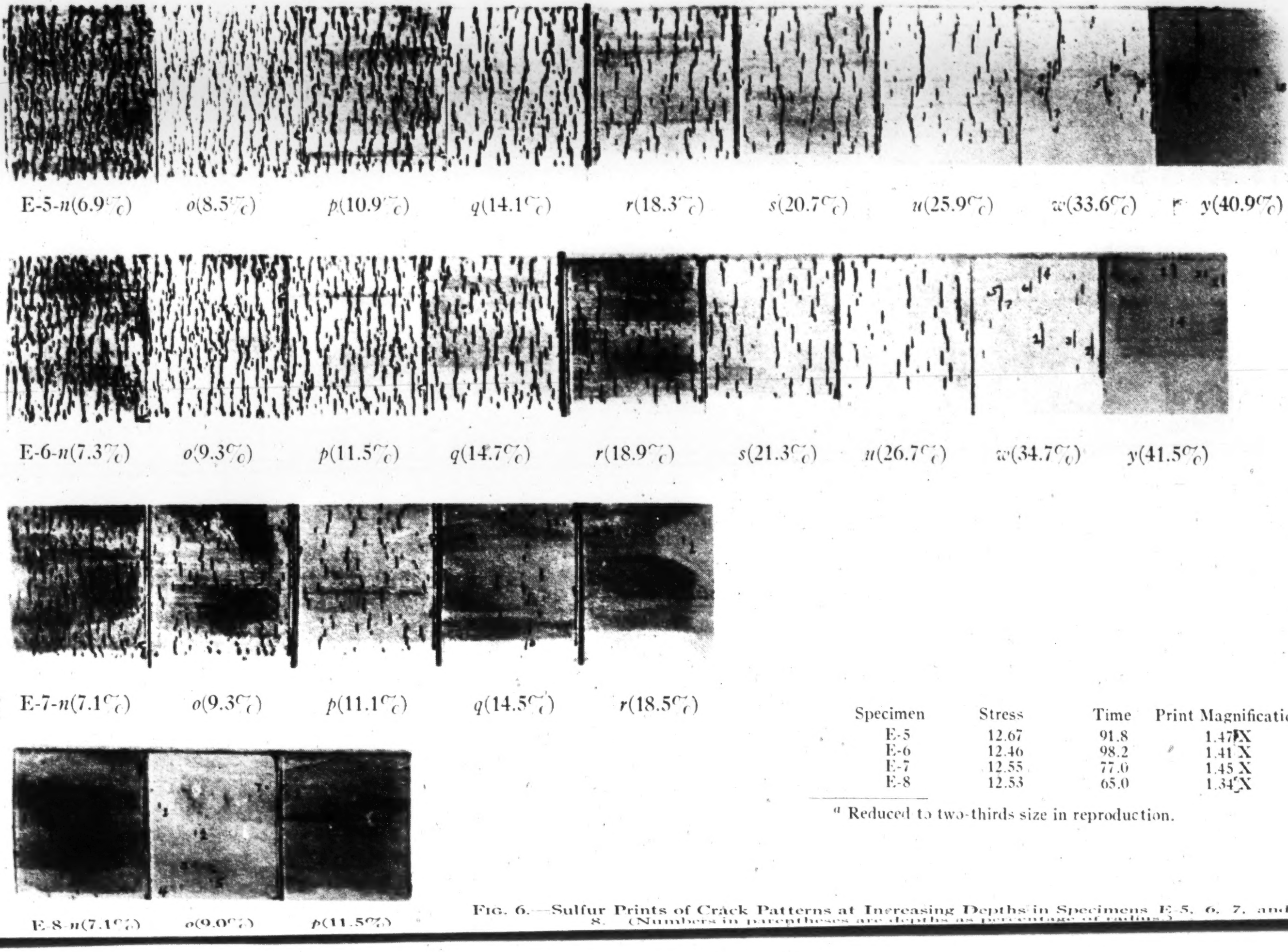
The following precautions are advisable:

(*a*) In making sulfur prints, use (for example) the left hand to hold only printing paper and paper towels. Use the right hand to hold the specimen. This was found almost necessary to avoid staining the photographic paper with Na_2S.

(*b*) Guard against lint from paper towels, etc., both on the specimen and printing paper. Lint from the specimen in particular stains the printing paper.

The author found it convenient to work with 5 to 15 specimen halves in a group. Small glass vials ($\frac{1}{2}$ by 2 in.) filled with HCl or Na_2S solution were used to soak the specimens. The vials were held in a wooden rack. Sulfur prints can be made very economically with a fairly large group of specimens.

In the sulfur printing process, corrosion products and iron sulfide probably fill the cracks and help to retain sodium sulfide, which gives an insoluble dark precipitate of silver sulfide in the photo-sensitive gelatin when contact occurs. The resulting sulfur print is a permanent record of the minute details of the crack pattern.


E-5-n(6.9%)
o(8.5%)
p(10.9%)
q(14.1%)
r(18.3%)
s(20.7%)
u(25.9%)
w(33.6%)
y(40.9%)
E-6-n(7.3%)
o(9.3%)
p(11.5%)
q(14.7%)
r(18.9%)
s(21.3%)
u(26.7%)
w(34.7%)
y(41.5%)
E-7-n(7.1%)
o(9.3%)
p(11.1%)
q(14.5%)
r(18.5%)
E-8-n(7.1%)
o(9.0%)
p(11.5%)

Specimen	Stress	Time	Print Magnification[a]
E-5	12.67	91.8	1.47X
E-6	12.46	98.2	1.41 X
E-7	12.55	77.0	1.45 X
E-8	12.53	65.0	1.34 X

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[a] Reduced to two-thirds size in reproduction.

FIG. 6.—Sulfur Prints of Crack Patterns at Increasing Depths in Specimens E-5, 6, 7, and 8. (Numbers in parentheses are depths as percentage of radius.)

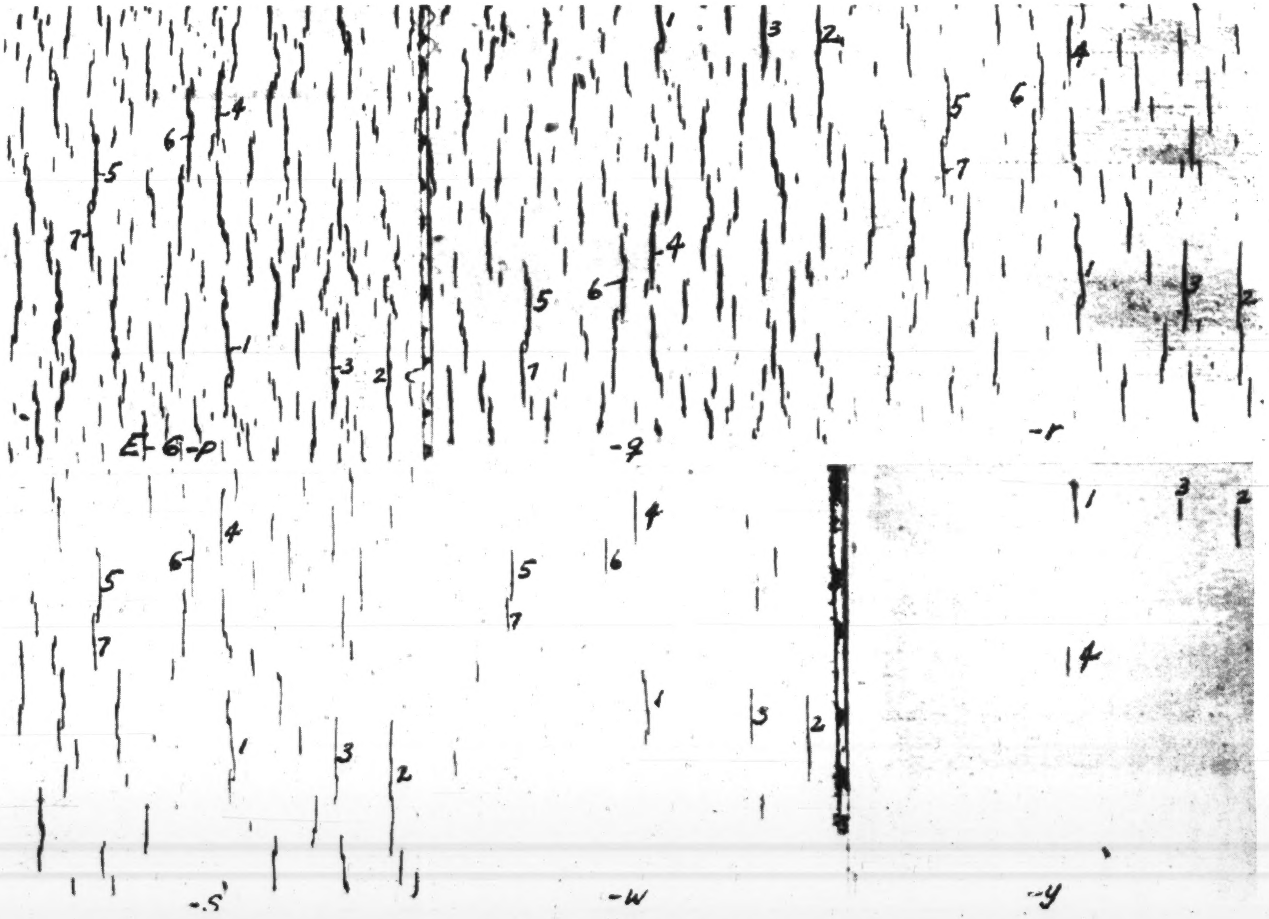

FIG. 7.—Photographs of Sulfur Prints as Used for Analysing (×3.8). (Reduced to 0.8 size in reproduction.)

METHOD FOR ANALYSING SULFUR PRINTS

After completion of the printing operations, series of sulfur prints made at successively greater radial depths were mounted and photographed. Several such series are shown in Fig. 6. Note the way in which the shallow cracks disappear and the deeper cracks maintain their identity and relative positions. Selected prints were photographically enlarged for study, as shown in Fig. 7. The method of analysis was as follows:

The deep cracks were taken to be the more important. These were the cracks that remained on the prints made at the greater depths. By examination of the latter prints, five to ten deep cracks were selected for study. These individual cracks were easily identified and labeled (numbered) on the prints made at the successively lesser depths, as shown in Figs. 6 and 7.

The lengths of the crack arcs, a_i, were measured from photographs such as Fig. 7. The angle α_i subtended by the i^{th} crack was calculated as:

$$\alpha_i = \frac{a_i}{M\pi d} \times 360 \text{ at a Percentage Depth} = \frac{d_o - d}{d_o} \times 100$$

where:

M = magnification of the photograph used,

d_o = original diameter of the specimen,

d = diameter of the cut specimen on which the particular print was made, and

i = 1, 2, 3, 4, etc., the number of any given crack being studied.

CRACK PROFILES

The calculations described above were collected in tabular form. Knowing α_i *versus* percentage depth for the cracks studied on a given specimen, it was possible to plot "crack profiles" on polar diagrams representing a cross-section of the specimens as shown in Figs. 8 and 9. The radial coordinate depth varies from 0 per cent at the virgin surface to 100 per cent at the center of the specimen. The angular coordinate is labeled as twice the geometrical angle represented since only the half profiles were shown. The crack profiles were drawn on the assumption of symmetry about radial lines. This tremendously simplified the measuring procedure and should not appreciably affect the crack depth indicated.

It was not possible to measure the profile shapes very near the surface because of the hopeless complication by net-works of pits and cracks. Some cracks were separated at the bottom and joined at the top and *vise versa*. The widths varied widely depending on the amount of joining which took place. Many cracks were "undercut"; that is, had arcs which subtended larger angles at greater depths (see Figs. 8 and 9). This undercutting was probably made possible by the stress relief in the heavily pitted and cracked material near the surface. Figure 9 shows one crack (No. 1) which evidently nearly cut the specimen in two pieces without causing failure. Another crack on specimen E-5 (92 hr., at 12,700 psi., not shown) subtended an angle of 205 deg. at a depth of 50 per cent, evidently cutting through the center of the specimen and yet failure occurred at another section.

RATE OF CRACK PENETRATION

It is evident that corrosion-fatigue cracks assume a wide variety of shapes and depths of penetration. At least two factors tend to produce variations in crack distribution and growth:

1. Corrosion pitting is almost unpredictable in nature and under corrosion-fatigue conditions lends a wide variety to the sizes, depths, and distribution of pits from which cracks grow.

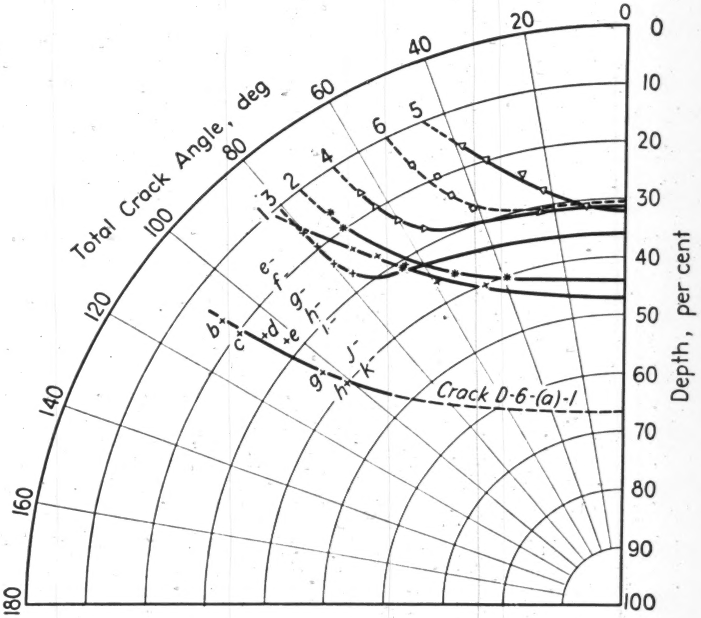

FIG. 8.—Crack Profiles, Specimen D-5. Stress 7800 psi. Time 173.7 hr.

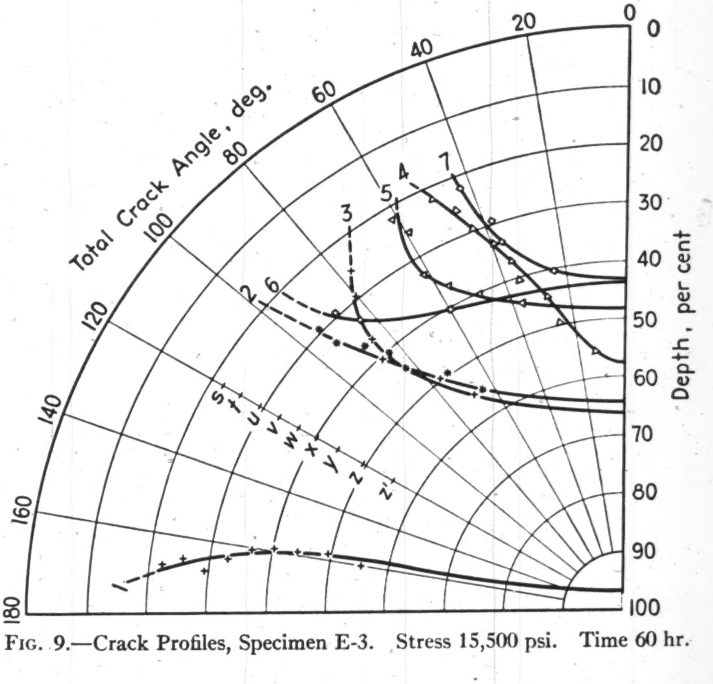

FIG. 9.—Crack Profiles, Specimen E-3. Stress 15,500 psi. Time 60 hr.

2. The process of crack growth is an unstable one. The greater the depth of a crack, the greater is the rate of its growth, and the smaller its depth, the smaller the rate of growth. The influence tends to increase the range of crack sizes.

The first problem has never received a satisfactory general solution. Extreme care should be exercised in duplicating experimental conditions and as many specimens as possible should be tested in order to determine the most probable results.

The second problem can be avoided almost entirely by limiting specimen damage to crack depths of not more than 25 per cent. The author found that the variety of crack depths and shapes is much less within this region and that beyond this depth the effects of instability are such as to make possible early failure. In practice a structure damaged to a comparable extent should be removed from service, and hence tests of longer duration are probably of secondary importance. Limiting the tests in this manner has the additional advantage of reducing fatigue machine operation time by about 40 per cent.

Figure 10 shows the range of depths in which the deepest five to ten cracks fall in specimens tested at 15,500 psi. for various lengths of time. The curves drawn for other stress levels were of similar shape. The main differences were in rates of increase of slope; the higher stresses caused higher rates of increase of slope and lower stresses, lower rates. At the lower stress levels, the results were more erratic (that is, there was more scatter or variety in crack depth) due to the relatively larger influence of corrosion in the corrosion-

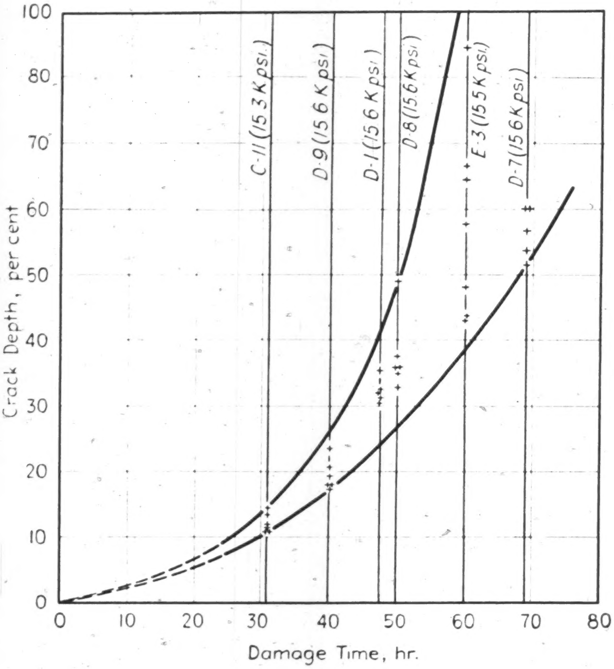

FIG. 10.—Crack Depth *Versus* Time, Specimens at 15,500 psi.

fatigue process. It should be noted that crack depth curves have no significance in the immediate neighborhood of the origin because of the time necessary for cracks to develop from corrosion pits. As has been mentioned, the earlier period of crack development is relatively important and deserved more attention than the author allowed in his own test program.

APPLICATIONS AND LIMITATIONS OF THE SULFUR PRINT METHOD

The value of the sulfur print has been established only for the type of test described in this paper. Sulfur prints allowed the author to study crack distribution, profile shapes, depths of penetration, and the rate of crack growth.

A similar procedure might facilitate study of the relative merits of materials, surface finishes, coatings and treatments in retarding crack growth and hence corrosion-fatigue damage.

"Size effect" in corrosion-fatigue specimens has received some attention in the engineering literature.[3] The question centers around the validity of comparison of test data obtained from specimens of different sizes.

Föppl, Behrens, and Dusold[4] have determined that shotblasting, if properly done, will increase the life of corrosion-fatigue specimens by as much as five times in some cases. It would be of interest to study the effect of shotblasting on the crack patterns and profiles formed in corrosion-fatigue.

Corrosion inhibitors are known to benefit corrosion-fatigue specimens,[5] but in some cases they promote localized corrosion. These tendencies could be studied to some advantage by the sulfur print method.

The shapes of quenching and grinding cracks could be studied by making sulfur prints of the damaged material at successive depths.

The sulfur print method does not constitute an "accelerated" test procedure. It does not make possible a "short cut" method of locating the *S-N* curve. It is probably more time-consuming than McAdam's method for evaluating corrosion-fatigue damage.

The destructive nature of the sulfur print method limits its application to laboratory tests.

The sulfur print method cannot be used to study the particular cracks that have caused failure in a specimen, since such cracks are at the ends of the broken halves. These ends are trimmed smooth in the test procedure.

It was found difficult to make good sulfur prints on diameters less than 0.2 in. The original specimen should thus be at least 0.4 in. in diameter to facilitate making prints at the greater depths.

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[4] O. Föppl, O. Behrens, and T. Dusold, *Zeitschrift fur Metallkunde*, Vol. 25, pp. 279–281 (1933).

[5] U. R. Evans, "The Passivity of Metals and Its Relation to Problems of Corrosion," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Inst. Met. Div., p. 7 (1929).

A THEORY OF THE MECHANISM OF RUSTING OF LOW ALLOY STEELS IN THE ATMOSPHERE

By H. R. Copson[1]

Synopsis

In 1941 exposure tests were started on low-alloy steels in industrial and marine atmospheres. Analyses of selected rust samples are presented, along with an examination of weather data and some weight losses. These results led to a new theory of the mechanism of rusting.

It is postulated that corrosion rate depends on the quality and quantity of water reaching the steel surface. Relatively insoluble corrosion products decrease the amount of soluble constituents in the water and thereby decrease corrosion. Relatively insoluble corrosion products do not wash away, and thereby they decrease the porosity of the rust coating and the quantity of water reaching the steel. As time goes on pores become plugged and the position of low-alloy steels improves.

In industrial atmospheres, copper and nickel in steel render sulfate corrosion products more insoluble by forming complex basic sulfates. On mild steel, sulfates in the rust are relatively soluble and promote corrosion but are washed away by rain. On alloy steels the sulfates are less soluble so that corrosion is slower, but less sulfate is washed away and more accumulates in the rust. The percentage of sulfates in the rust *increases* as weight loss *decreases*. At the marine location, severe corrosion of certain edges was due to soluble chlorides being swept to these edges by the wash of rain.

Miscellaneous data and references are examined in the light of this mechanism. A factor which has been neglected in the literature is the composition of the film of electrolyte on the steel surface. It has been tacitly assumed that in a given atmosphere each test specimen of steel is exposed to the same environment. Actually, owing to the influence of corrosion products, each steel specimen is exposed to a separate environment.

It has long been known that the composition of steel affects the rate of corrosion in the atmosphere (**1**).[2] There is a wealth of data showing that fractional percentages of copper markedly decrease corrosion (**2**). While there has been widespread interest in this phenomena, the mechanism has never been fully understood (**3, 4**). Carius (**5**) has proposed that resistance to atmospheric corrosion is increased by the formation of a copper or copper-rich layer next to the steel, but as will be shown there are serious reasons to doubt this.

Many authors have noted differences in the visual appearance of rust coatings and have felt that corrosion rate was controlled by the protective quality of the rust. The typical appearance of some 3-yr. old rust coatings at Bayonne, N. J., is shown in Fig. 1. There is little doubt about which specimens corrode faster. As corrosion resistance increases, the rust becomes darker in color, finer in texture, and apparently thinner and more adherent. As long ago as 1921 Richardson (6) stated the situation as follows, "The 'rust effect' is of far greater importance than the composition of the metal in determining the life of a sheet undergoing atmospheric corrosion, although in some unknown way composition in part determines the course of the 'rust effect.' "

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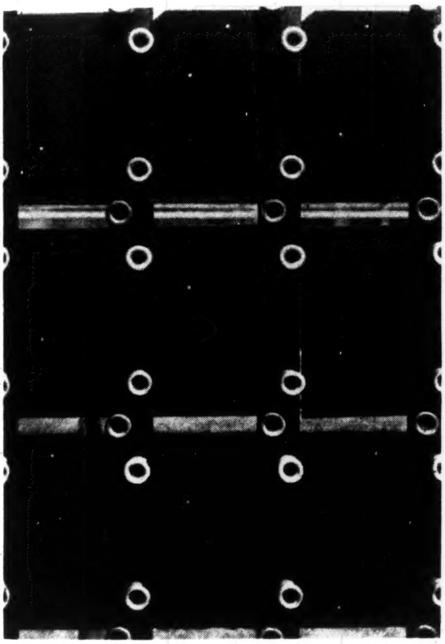
[1] Research Chemist, Research Lab., The International Nickel Company, Inc., Bayonne, N. J.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 579.



Steel Number

16-1	50	45
34	20	54
33	1	58

FIG. 1.—Appearance of Skyward Surface of 4 by 6 in. Steel Specimens after 3 yr. Atmospheric Exposure at Bayonne, N. J. Analyses in Table I.

Schramm and Taylerson (7) pointed out a number of factors of importance in the atmospheric corrosion of steel, and stated, "The presence of moisture on the surface of steel, or in the rust film which subsequently forms, furnishes ideal conditions for the absorption of acid-forming constituents from an industrial atmosphere. These substances promote corrosion either by direct chemical action or by reducing the resistance of electrolytic cells which may form on the surface. The presence of a white deposit in the drainage area of samples has been repeatedly observed; this probably consists largely of ferric sulfate, an exceptionally corrosive salt resulting from the oxidation of the original corrosion products. Heavy rains may dissolve and remove all of the soluble salts."

Finkeldey (8) also called attention to the beneficial action of rainfall, ". . . in industrial atmospheres, heavy rains may even be protective to metals rather than otherwise, since they wash an exposed surface free from accumulations of soot and dust particles which hold moisture and also serve to promote the condensation of industrial gases such as SO_2 and probably function as a catalyzer in converting it to SO_3."

Larrabee (9) attributed the slower corrosion of skyward surfaces as compared with groundward surfaces of inclined specimens to the wash of rain. "As a result, the sulfur compounds, which are believed to be largely responsible for the severity of atmospheric corrosion (in locations removed from the sea), are washed away to a greater extent than on the groundward side which is wet by dew, but not 'washed' by rain."

The work of these authors and of others aided in the development of the mechanism of rusting described below.

ATMOSPHERIC TESTS STARTED IN 1941

Five sets of 71 low-alloy structural steels were exposed to the atmosphere in May, 1941, at two locations. It is planned to obtain weight loss *versus* time curves on these steels, and already some weight losses have been determined at 1 and 3 yr. It is not the purpose of this paper to present these weight loss data; it is planned to publish them at a later date when the tests are more mature. Nevertheless information gathered in the course of conducting this 1941 series of tests led to the development of the new mechanism of rusting. Such of this information as is necessary to understanding the mechanism will be presented at this time. The analyses of the steels included are given in Table I.

One of the locations was in the yard of this laboratory at Bayonne, N. J., not far from the center of oil refining activity. This is considered an industrial atmosphere. The other location was at Block Island, R. I. The test site is about 15 miles from the mainland and is remote from manufacturing centers. This is considered a marine atmosphere.

TABLE I.—ANALYSES OF STEELS.

Steel	Group	Description	Analysis, per cent									
			Carbon	Manganese	Silicon	Sulfur	Phosphorus	Nickel	Copper	Chromium	Molybdenum	Vanadium
No. 44	I	High purity iron, plus copper	0.016	0.016	0.002	0.03	0.005	<0.05	0.014			
No. 45			0.020	0.020	0.003	0.03	0.006	<0.05	0.020			
No. 63			0.020	0.023	0.002	0.03	0.005	<0.05	0.053			
No. 54			0.02	0.07	<0.01	0.03	0.003	0.18	0.10			
No. 55			0.01	0.06	<0.01	0.03	0.003	0.13	0.27			
No. 10	II	Copper steel, low phosphorus	0.041	0.22	0.002	0.04	0.010	<0.05	0.02	0.01		
No. 31			0.09	0.35	0.05	0.02	0.009	<0.05	0.041			
No. 5			0.043	0.39	0.007	0.02	0.007	0.01	0.05	0.07		
No. 57			0.06	0.26	0.01	0.03	0.007	0.06	0.19		<0.01	
No. 6			0.046	0.40	0.005	0.02	0.007	0.000	0.21	0.07		
No. 64			0.026	0.24	0.004	0.04	0.009	<0.05	0.265			
No. 40			0.03	0.17	<0.01	0.03	0.006	<0.05	0.27			
No. 58			0.05	0.31	0.01	0.02	0.008	<0.05	0.27			
No. 56			0.04	0.31	0.01	0.02	0.004	0.05	0.30		<0.01	
No. 7			0.038	0.40	0.004	0.02	0.008	0.004	0.50	0.07		
No. 1	III	Copper, steel, high phosphorus	0.085	0.43	0.005	0.05	0.103	0.002	0.01	0.02		
No. 11			0.040	0.49	0.003	0.04	0.074	0.01	0.05	0.10	<0.003	
No. 12			0.026	0.47	0.003	0.06	0.066	0.03	0.27	0.03	<0.003	
No. 16			0.09	0.43	0.005	0.03	0.058	0.24	0.36	0.06		
No. 18	IV	Copper steel, high manganese and silica	0.33	0.78	0.31	0.04	0.043	0.03	0.03	0.06		
No. 19			0.16	1.32	0.24	0.03	0.018	0.03	0.03	0.12		0.093
No. 17			0.25	1.35	0.18	0.03	0.022	0.01	0.28	0.03		
No. 32	VII	Nickel steel	0.11	0.69	0.14	0.02	0.011	0.20	0.038			
No. 27			0.16	0.56	0.23	0.03	0.013	0.54	0.12	0.05		
No. 33			0.14	0.37	0.07	0.02	0.008	0.55	0.03			
No. 34			0.14	0.36	0.37	0.02	0.008	1.27	0.028			
No. 28			0.14	0.47	0.23	0.02	0.014	1.47	0.03	0.05		
No.147			0.06	0.14	0.14	0.03	0.013	1.96	0.03			
No. 46			0.16	0.57	0.20	0.02	0.015	2.20	0.24			
No. 35			0.14	0.28	0.08	0.02	0.008	2.55	0.03			
No. 20			0.19	0.53	0.009	0.02	0.016	3.23	0.07			
No. 62			0.17	0.58	0.26	0.01	0.007	4.98	0.09			
No. 30	VIII	Nickel steel plus chromium	0.13	0.45	0.23	0.03	0.017	1.18	0.04	0.65	<0.01	
No. 29	IX	Nickel steel plus molybdenum	0.16	0.53	0.25	0.01	0.013	1.84	0.03	0.09	0.24	
No. 51	X	Nickel steel plus chromium and molybdenum	0.10	0.59	0.49	0.01	0.013	1.62	0.09	1.01	0.21	
No. 52			0.08	0.57	0.33	0.01	0.015	1.34	0.19	0.74	0.25	
No. 60	XI	Nickel copper steel	0.12	0.57	0.17	0.02	0.01	1.00	1.05			
No.148			0.05	0.17	0.13	0.03	0.014	1.05	0.89			
No. 50			0.09	0.48	1.00	0.03	0.055	1.14	1.06			
No. 16-1	XII	Nickel copper steel plus chromium	0.044	0.02	0.003	0.02	0.010	0.49	0.54	0.46		
No. 47			0.11	0.75	0.23	0.04	0.020	0.65	0.53	0.74		

The specimens were mounted on metal racks similar to those designed by Taylerson of Carnegie Illinois Steel Corp. (**10**), and used by that corporation (**9**) and by the Joint Committee on Electrodeposited Coatings on Steel of the A.S.T.M. and American Electroplaters' Society (**11**). Part of the racks at Bayonne is shown in Fig. 2. The 4 by 6-in. specimens were supported on Monel frames by means of porcelain insulators, which prevented contact with any metal. The frames were attached to galvanized iron supports so that the specimens were inclined 30 deg. from the horizontal and faced south. The specimens were identified by a two-hole numbering system. All specimens were pickled clean before exposure.

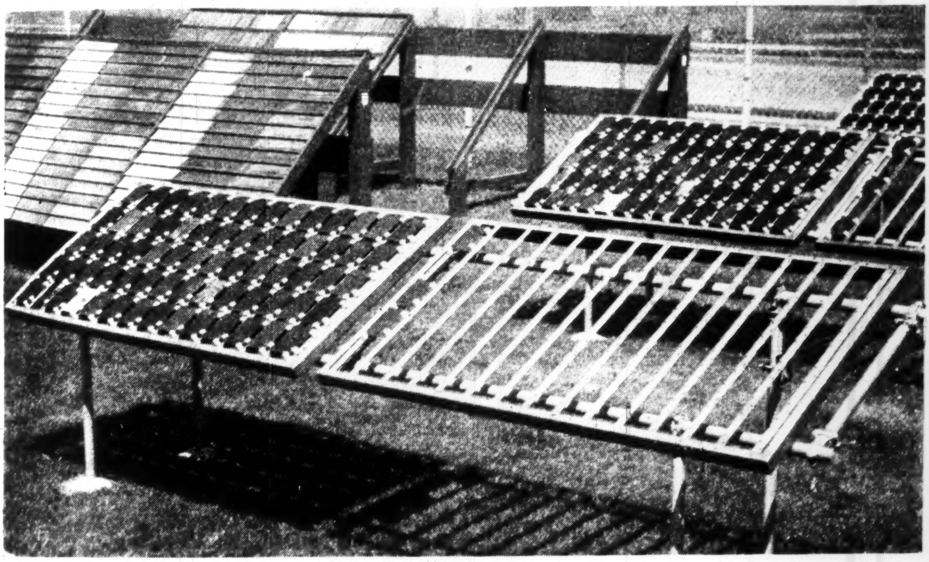


FIG. 2.—Part of the Atmospheric Corrosion Racks at Bayonne with 4 by 6 in. Steel Specimens Installed.

ANALYSES OF RUST

Analyses of 1-yr. Rusts—Table II:

In order to have a comparison between the two atmospheres it was decided in April, 1944, to determine the amount of sulfate and chloride in typical Bayonne and Block Island rusts. Some loose 1-yr. rusts had been saved and were still available. The voluminous rust from a fast corroding steel, No. 44, and a composite rust sample from some steels averaging 0.053 per cent copper were analyzed. At the same time the opportunity was taken to determine the copper to iron and the nickel to iron ratio in some other composite rust samples.

The results in Table II were entirely different than expected. There was more sulfate in the rust from the industrial atmosphere and more chloride in the rust from the marine atmosphere as expected, but the composite rust from the 0.05 per cent copper steels contained more moisture, more sulfate, and more chloride than the rust from the fast corroding steel. All the chloride percentages were low, but even in the marine Block Island air the 0.05 per cent copper steels collected plenty of sulfate. The figures for copper and nickel gave no

TABLE II.—ANALYSES OF 1-YR. RUSTS.

Bayonne.—May 12, 1941 to May 14, 1942—1.00 yr.
Block Island.—May 28, 1941 to July 7, 1942—1.11 yr.

Rust		Analysis of Rust, per cent						Average 1-yr. Weight Loss of Steels, g.	Comparison of Copper or Nickel in Rust with Copper or Nickel in Steel			
			Dry Basis									
Composite Loose Rust From Upper and Lower Surfaces of Steels	Location	H_2O at 110C.	SO_4	Chlorine	Iron	Copper	Nickel		Copper or Nickel in Steels Avg., per cent	Iron in Steels, Avg., per cent	Cu/Fe or Ni/Fe Ratio in Steels	Cu/Fe or Ni/Fe Ratio in Rusts
No. 44	Bayonne	1.82	0.87	0.001	...	...	...	52.3	0.014 Cu.	99.91		
No. 44	Block Island	2.12	0.08	0.018	...	...	...	211.2	0.014 Cu.	99.91		
Nos. 11, 18, 19, 54, 63	Bayonne	2.76	2.47	0.008	...	...	...	16.4	0.053 Cu.	98.99		
Nos. 11, 18, 19, 54, 63	Block Island	3.37	0.94	0.048	...	...	...	13.4	0.053 Cu.	98.99		
Nos. 12, 40, 55, 58, 64	Bayonne	2.56	...	...	58.8	0.13	...	12.4	0.27 Cu.	99.37	0.0027	0.0022
Nos. 12, 40, 55, 58, 64	Block Island	3.31	...	...	59.4	0.10	...	12.0	0.27 Cu.	99.37	0.0027	0.0017
Nos. 28, 30, 34, 51, 52	Bayonne and Block Island	3.15	...	...	57.3	...	0.61	8.5	1.26 Ni.	97.12	0.0130	0.0106

TABLE III.—ANALYSES OF 2-YR. BAYONNE RUSTS.

Exposed, May 15, 1942. Removed, May 2, 1944 to June 8, 1944.—1.97 to 2.07 yr.

Steel	Rust			Analysis of Rust, per cent					Average 2-yr. Weight Loss of Steels, g.	Comparison of Copper or Nickel in Rust with Copper or Nickel in Steel			
					Dry Basis								
	Location	Specimen	Weight, g.	H_2O at 110C.	SO_4	Iron	Copper	Nickel		Copper or Nickel in Steel, per cent	Iron in Steel, per cent	Ni/Fe or Cu/Fe Ratio in Steel	Cu/Fe or Ni/Fe Ratio in Rust
No. 44	Loose rust from skyward surface	A5-C9 A5-C7 A5-C8	43.5 46.8 24.4	2.28 2.33 2.41	0.94 0.90 0.91	61.6			128.6	0.014 Cu	99.91	0.0001	
	Loose rust from groundward surface	A5-C9 A5-C7 A5-C8	85.2 94.1 91.7	1.91 2.23 2.32	0.87 0.87 0.90	63.9							
	Adherent rust, both surfaces	A5-C9 A5-C7	32.9 26.7		0.48^a	62.4^a							
No. 7	Loose upper	A6-A9	0.4	2.45	3.05	55.0	0.19		14.6	0.50 Cu	98.95	0.0051	0.0035
	Loose lower	A6-A9	1.2	3.23	3.24	56.9	0.22						0.0039
	Adherent	A6-A9 A5-D9	10.7 10.9		2.06^a	55.6^a 57.9^a	0.16^a						0.0029
No. 28	Loose upper	A6-B5	0.3	2.75	3.27	53.6		0.31	11.7	1.47 Ni	97.57	0.0151	0.0058
	Loose lower	A6-B5	0.9	4.08	3.99	55.1							
	Adherent	A6-B5 A6-B4	9.9 9.1		2.51^a	58.6^a 55.2^a		0.93^a					0.0159

[a] These rusts were not dried.

indication that these elements were accumulating in the rust. In fact some copper and nickel seemed to have been lost from the outer loose rust.

After mulling over the figures for some time, a mechanism explaining them was originated. As has been pointed out, rust may contain soluble corrosive sulfates, and these may be washed away by rain. It was conceived that perhaps the function of copper was to render the sulfates insoluble, probably by forming complex basic sulfates. This seemed reasonable because the patina on pure copper is mostly basic copper sulfate. Then in the case of very low-copper steels, such as steel No. 44, the sulfates are relatively soluble and promote corrosion but are washed away by rain. In the case of higher copper steels, the sulfates are less soluble so that corrosion is slower, but by the same token less sulfate is washed away and the sulfate content of the rust builds up to higher values. The same mechanism seemed to apply to the chlorides as well, but since chlorides are more soluble less remained in the rust.

Analyses of 2-yr. Bayonne Rusts—Table III:

If the mechanism just postulated was correct, the rust on the sheltered groundward surface should contain more sulfate than the skyward surface. There were available for analysis some 2-yr. old rust crops on a few steel specimens which had been put out for the specific purpose of growing rust. Accordingly analyses were made on rust collected from a very pure ingot iron, No. 44, a 0.5 per cent copper steel, No. 7, and a 1.5 per cent nickel steel, No. 28.

The results were gratifying. The rust from the groundward surfaces of the copper and nickel steels contained more moisture and sulfate than the rust from the skyward surfaces. This did not apply in the case of the ingot iron, but this material contained no addition elements likely to render sulfate more insoluble.

The results on the nickel steel showed that the mechanism applied to nickel additions as well as to copper. The nickel steel had the lowest weight loss and its rust contained more moisture and sulfate than the rust on the copper steel. The rust on the copper steel in turn had more moisture and sulfate than the rust on the ingot iron. The fact that the moisture content paralleled the sulfate content would seem to indicate that the basic sulfates had some loosely held water of crystallization.

The mechanism suggests that the composition of the film of electrolyte on the specimen may vary with the weather. However, since the amount of soluble material present at one time is quite small, it is doubtful whether this can be shown by analyzing the rust. Nevertheless an attempt was made in the case of steel No. 44. The rust on specimen A5-C7 was analyzed after an 8-day dry spell and on specimen A5-C8 after 0.60 in. of rain broke the dry spell. The results in Table III show no significant variation in the analysis of the rust. Steel No. 44 may have been a poor one to try.

So far only the outer loose rust had been analyzed. Since this made up only a small fraction of the total, it was desirable to extend the analyses to the adherent rusts. This was accomplished in the case of steels Nos. 44, 7, and 28 by removing the adherent rust by cathodic treatment in 6 per cent hydrochloric acid using nickel anodes and analyzing the solutions. The results in Table III show that the adherent rust contained somewhat less sulfate than the outer rust, but the steels were again lined up in the same order.

The copper and nickel in the adherent rusts were determined by cathodic treatment in 6 per cent sulfuric acid using lead anodes and analyzing the solutions. The copper and nickel contents of the loose rusts were also determined. The results failed to show any real concentration of copper or nickel in the outer loose rust or in the adherent rust.

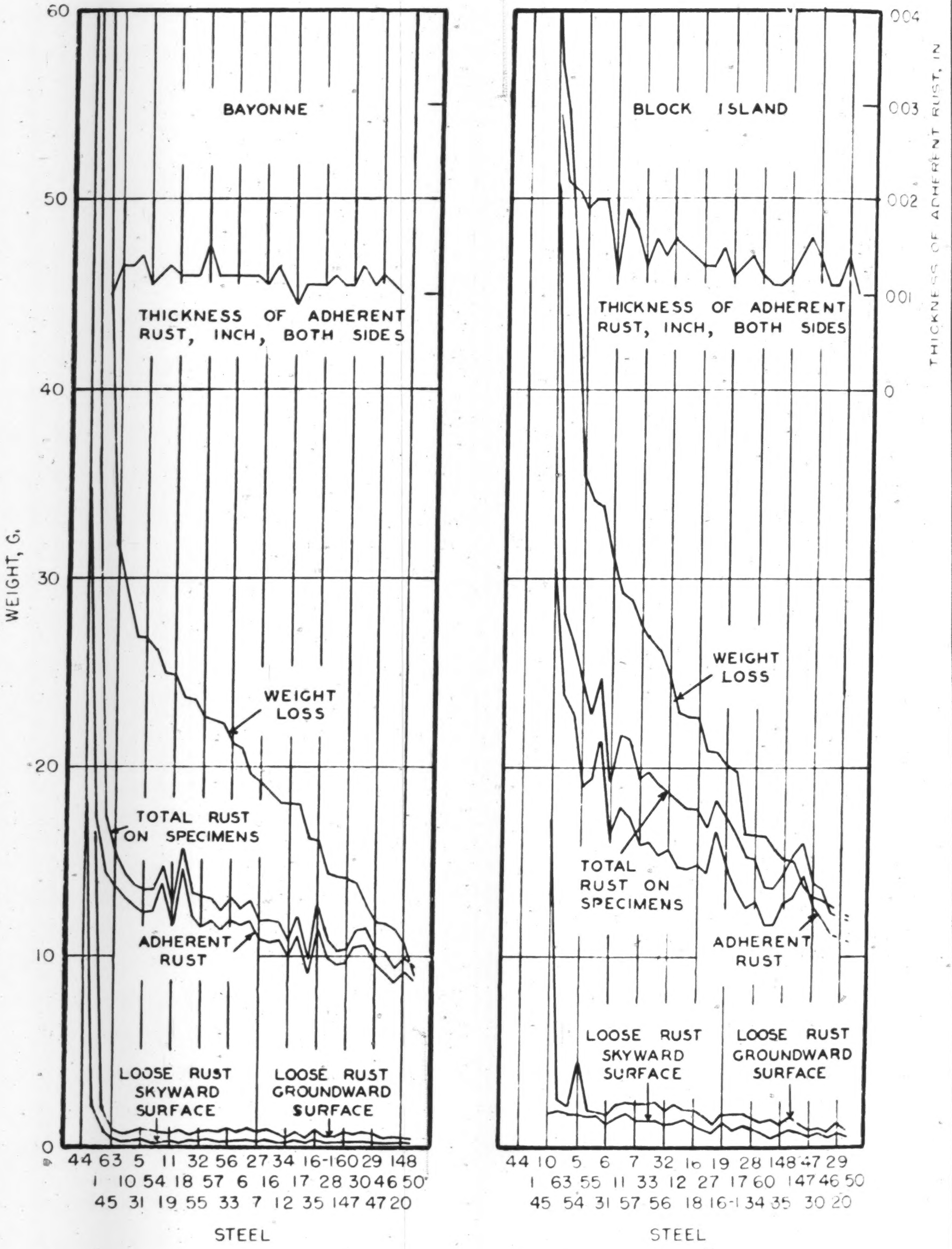


FIG. 3.—Weight and Thickness of Rust on Specimens, 3 yr.

Weight of Rust on 3-yr. Specimens—Fig. 3:

In order to have a better conception of the portion of the rust being analyzed, some weight determinations were made on specimens which were being cleaned up after 3 yr. of exposure. After the specimens were removed from the racks, they were weighed with the rust intact, with the loose rust scraped off, and after complete cleaning. Thus were obtained the total weight of rust on the specimens, the weight of adherent rust, the weight of loose rust on the skyward surface, and the weight of loose rust on the groundward surface. While doing this micrometer measurements were made, so that the approximate thicknesses of the rust coatings were obtained. The results are plotted in Fig. 3 where the steels are arranged in the order of their decreasing 3-yr. weight loss.

Since the rust was found to run 54 to 64 per cent in iron, it is evident that a large part of the rust had departed from the specimens. The corrosion-resistant steels retained more of their rust, but the actual weight of rust was greater on the fast corroding steels.

Only a small portion of the rust on the specimens was loose enough to be scraped off. There was more loose rust on the groundward surface than on the skyward surface. At 3 yr. there was more rust

TABLE IV.—ANALYSES OF 3-YR. BAYONNE RUSTS.
Exposed, May 12, 1941. Removed, May 16, 1944—3.0 yr.

Rust					Analysis of Rust, per cent					3-yr. Weight Loss of Steels, g.	Comparison of Copper or Nickel in Steel with Copper or Nickel in Rust			
						Dry Basis								
Location	Steel	Group	Specimen	Weight, g.	H_2O at 110C.	SO_4	Iron	Copper	Nickel		Copper or Nickel in Steel, per cent	Iron in steel, per cent	Cu/Fe or Ni/Fe Ratio in Steel	Cu/Fe or Ni/Fe Ratio in Rust
Loose rust from groundward surface	No. 44	I	A5-J2	120.8	1.85	0.94				182.8	0.014 Cu	99.91	0.0001	
	No. 45		A5-K2	2.0	3.46	2.82				44.4	0.020 Cu	99.89	0.0002	
	No. 63		A7-H2	0.8	3.58	3.36				31.7	0.053 Cu	99.86	0.0005	
	No. 54		A6-J2	0.8	3.65	3.44				26.2	0.10 Cu	99.59	0.0010	
	No. 55		A6-K2	0.5	3.61	3.48				23.5	0.27 Cu	99.49	0.0027	
	No. 10	II	A1-P2	0.7	3.76	3.51	56.2	0.026		29.2	0.02 Cu	99.61	0.0002	0.0005
	No. 31		A4-F2	0.8	3.93	3.63	56.8	0.044		27.0	0.04 Cu	99.39	0.0004	0.0008
	No. 5		A1-J2	0.8	3.93	3.61	57.1	0.032		26.9	0.05 Cu	99.40	0.0005	0.0006
	No 57		A6-M2	0.8	3.87	3.59	56.6	0.064		22.5	0.19 Cu	99.38	0.0019	0.0011
	No 6		A1-K2	0.7	3.56	3.70	57.8	0.11		21.0	0.21 Cu	99.24	0.0021	0.0019
	No. 56		A6-L2	0.9	3.35	3.54	56.3	0.14		21.2	0.30 Cu	99.26	0.0030	0.0025
	No. 7		A1-L2	0.9	3.30	3.66	56.2	0.21		19.5	0.50 Cu	98.95	0.0051	0.0037
	No. 1	III	A1-E2	17.7	2.63	1.23				101.0	0.01 Cu	99.29	0.0001	
	No. 16		A2-K2	0.9	3.52	3.81	56.3	0.15		18.6	0.36 Cu	98.73	0.0036	0.0027
	No. 32	VII	A4-G2	0.7	3.71	3.95	56.3		0.16	22.7	0.20 Ni	98.79	0.0020	0.0028
	No. 27		A3-M2	0.8	4.11	3.98	55.7		0.33	19.1	0.54 Ni	98.29	0.0055	0.0059
	No. 33		A4-H2	0.8	4.02	3.96	56.2		0.31	22.4	0.55 Ni	98.81	0.0056	0.0055
	No. 34		A4-J2	0.4	4.47	4.41	55.4		0.69	18.0	1.27 Ni	97.80	0.0130	0.0125
	No. 28		A3-N2	0.5	4.15	4.31	55.3		0.75	14.3	1.47 Ni	97.57	0.0151	0.0136
	No. 147		A7-N2	0.5	4.39	4.54	54.8		0.99	14.2	1.96 Ni	97.62	0.0200	0.0181
	No. 46		A5-L2	0.4	4.22	4.17	54.9		1.01	11.7	2.20 Ni	96.59	0.0228	0.0184
	No. 35		A4-K2	0.3	4.50	4.62	54.4		1.23	16.1	2.55 Ni	96.89	0.0263	0.0224
	No. 20		A3-E2	0.5	4.61	4.64	53.7		1.35	11.4	3.23 Ni	95.93	0.0336	0.0251
Loose rust from skyward surface	No. 10	II	A1-P2	0.1	3.02	2.72				29.2				
	No. 31		A4-F2	0.2	3.33	3.13				27.0				
	No. 5		A1-J2	0.3	3.51	3.04				26.9				
	No. 57		A6-M2	0.3	2.93	3.10				22.5				
	No. 6		A1-K2	0.3	2.26	3.22				21.0				
	No. 56		A6-L2	0.2	2.54	2.93				21.2				
	No. 7		A1-L2	0.3	2.33	3.06				19.5				

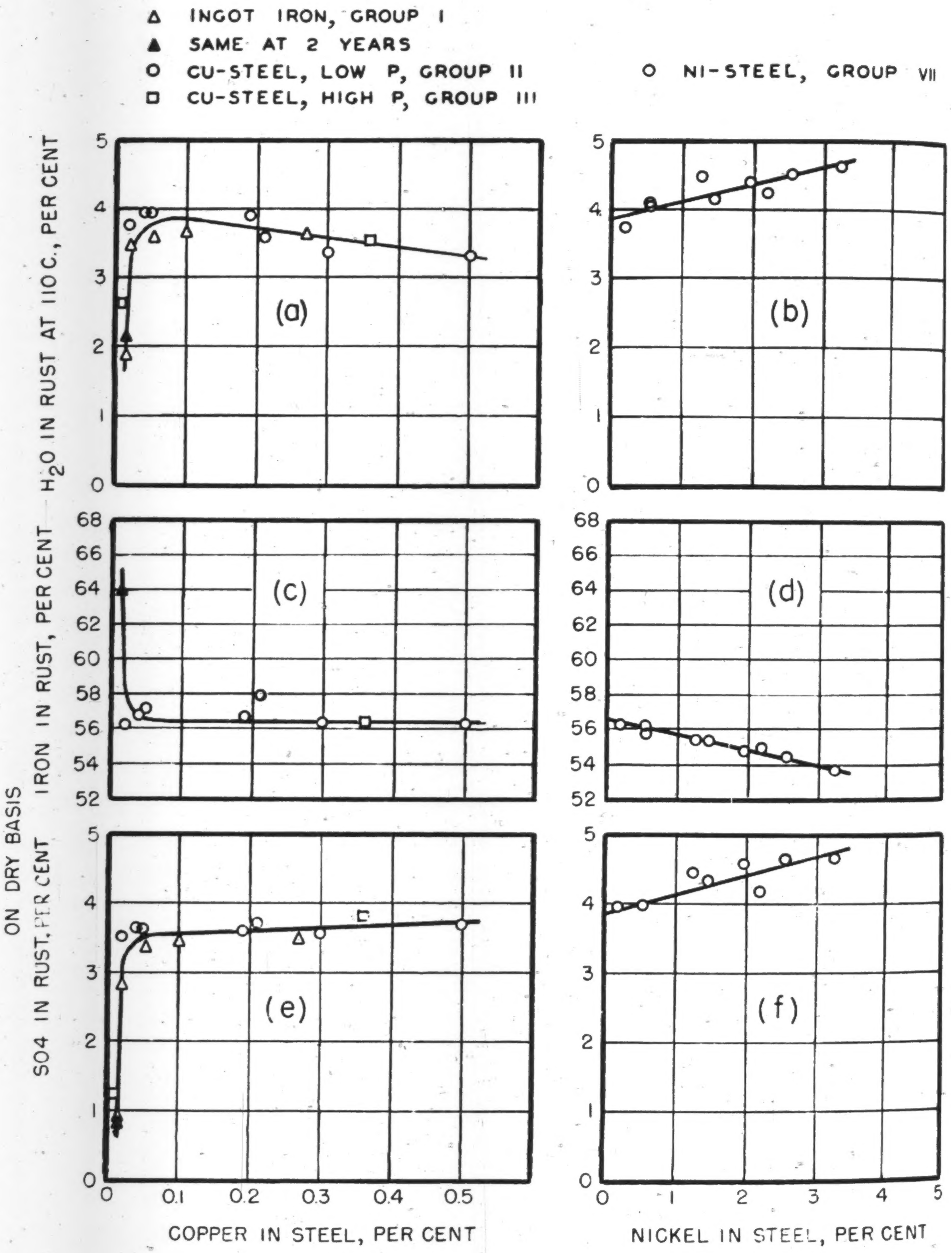


FIG. 4.—Percentage H_2O Iron and SO_4 in Loose 3-yr. Rust from Groundward Surface of Bayonne Steels.

of all types on the Block Island specimens than on the Bayonne specimens.

Micrometer measurements showed that the adherent rust was about 0.005 in. thick. The figures were not accurate enough to warrant calculating the density of the rust.

Analyses of 3-yr. Bayonne Rusts—Table IV:

It seemed desirable to extend the analyses to a considerable number of copper and nickel steels. Accordingly analyses were made on the loose rust collected from the skyward and groundward surfaces of the 3-yr. Bayonne specimens. As can be seen from Fig. 3 only a small portion of the total rust was analyzed. Most of the analyses were made on samples from groundward surfaces for the simple reason that these samples weighed more. For comparison the skyward rust on the group II steels was analyzed. As before the skyward rust contained less moisture and sulfate than the groundward rust.

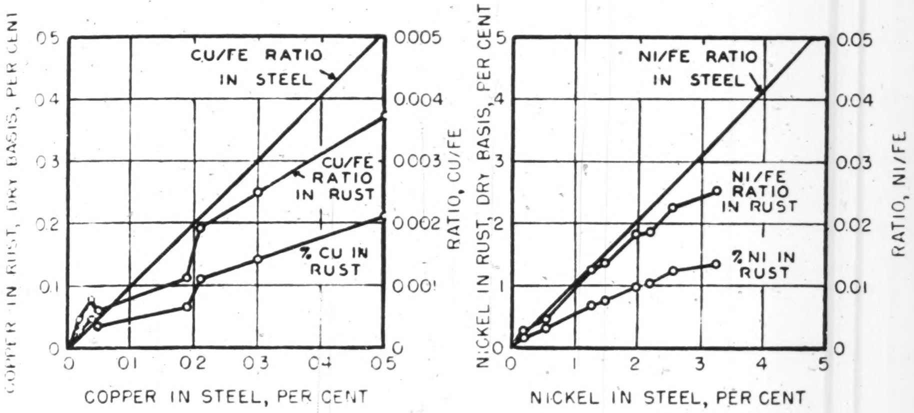


FIG. 5.—Copper and Nickel in Loose 3-yr. Bayonne Rust from Groundward Surface.

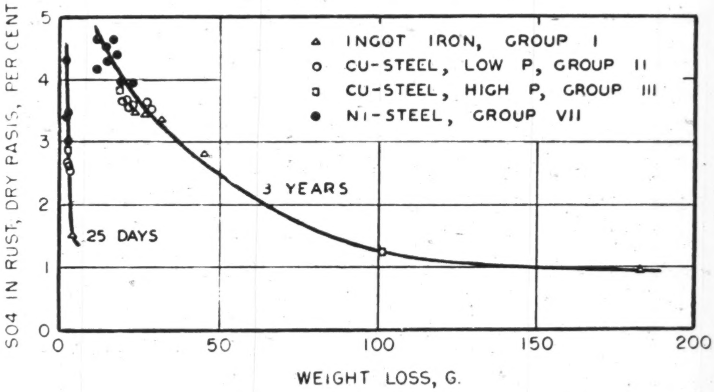


FIG. 6.—Weight Loss *Versus* Percentage SO_4 in Loose Rust from Groundward Surface of Bayonne Steels.

In Fig. 4 the moisture, iron, and sulfate contents of the groundward rusts are plotted against the copper and nickel contents of the steels. In the case of the copper steels there is an inflection point at about 0.03 per cent copper. This is lower than the inflection point of weight-loss copper-content curves, which at Bayonne seems to occur at about 0.2 per cent copper (12). The significance of this difference is not clearly understood.

In the case of the nickel steels all the points lie close to straight lines. All the nickel steels contained at least 0.03 per cent copper. As the nickel content of the steel increases, the moisture and sulfate contents of the rust increase and the iron content decreases. The sulfate content reached a high of 4.64 per cent and probably goes above 5 per cent in 5 per cent nickel steel. In the case of these 3-yr. old rusts the decrease in iron content is accounted for almost entirely by the increase in moisture, sulfate, and nickel content of the rust, that is the sum of the iron, nickel, moisture, and sulfate in the rust is substantially constant. This applies also to the copper steels. Nevertheless the variation in iron content is large, being from 64 to 54 per cent.

Figure 5 shows the copper-iron and nickel-iron ratios in the steel. Except at very low percentages both nickel and copper have been lost from the outer loose rust.

Figure 6 shows a plot of the percentage of sulfate in the rust against weight loss. This curve is very convincing. At 3 yr. there is no doubt but that increased corrosion resistance is paralleled by increased sulfate in the rust.

TABLE V.—ANALYSES OF 25-DAY BAYONNE RUSTS.

Exposed, June 8, 1944. Removed, July 3, 1944—25 days

Rust					Analysis of Rust, per cent						Comparison of Copper or Nickel in Steel with Copper or Nickel in Rust			
						Dry Basis								
Location	Steel	Group	Specimen	Weight of Rust, g.	H_2O at 110C.	SO_4	Iron	Copper	Nickel	25-day Weight Loss of Steels, g.	Copper or Nickel in Steel, per cent	Iron in Steel, per cent	Cu/Fe or Ni/Fe Ratio in Steel	Cu/Fe or Ni/Fe Ratio in Rust
Loose rust from skyward surface	No. 44	I	A1-E6	1.45	3.31	1.53	60.8			3.98	0.014 Cu	99.91	0.0001	
	No. 5	II	B3-D6	0.67	3.48	2.16	59.0	0.06		2.50	0.05 Cu	99.40	0.0005	0.0010
	No. 6		A1-E7	0.39	3.28	2.09	58.0	0.14		2.03	0.21 Cu	99.24	0.0021	0.0024
	No. 7		A1-E8	0.55	2.91	2.08	58.5	0.18		2.52	0.50 Cu	98.95	0.0051	0.0031
	No. 16	III	A1-E9	0.31	3.03	2.30	57.6	0.19		2.18	0.36 Cu	98.73	0.0036	0.0033
	No. 27	VII	A1-F6	0.36	3.27	2.43	57.3		0.36	2.26	0.54 Ni	98.29	0.0055	0.0063
	No. 28		A1-F7	0.38	3.31	2.54	56.0		0.95	1.99	1.47 Ni	97.57	0.0151	0.0170
	No. 46		A1-F8	0.19	2.86	2.58	54.9		1.19	2.03	2.20 Ni	96.59	0.0228	0.0216
	No. 62		A1-F9	0.24	4.38	3.24	53.7		1.99	1.78	4.98 Ni	93.89	0.0531	0.0370
Loose rust from groundward surface	No. 44	I	A1-E6	1.99	2.41	1.51	61.8			3.98	0.014 Cu	99.91	0.0001	
	No. 5	II	B3-D6	1.30	2.91	2.62	60.3	0.02		2.50	0.05 Cu	99.40	0.0005	0.0003
	No. 6		A1-E7	0.72	3.09	2.67	59.7	0.04		2.03	0.21 Cu	99.24	0.0021	0.0007
	No. 7		A1-E8	1.23	2.75	2.53	59.6	0.16		2.52	0.50 Cu	98.95	0.0051	0.0027
	No. 16	III	A1-E9	0.80	3.35	2.88	59.9	0.13		2.18	0.36 Cu	98.73	0.0036	0.0022
	No. 27	VII	A1-F6	0.75	3.58	3.02	59.0		0.40	2.26	0.54 Ni	98.29	0.0055	0.0068
	No. 28		A1-F7	0.71	4.17	3.40	58.1		1.11	1.99	1.47 Ni	97.57	0.0151	0.0191
	No. 46		A1-F8	0.35	4.78	3.49	60.0		1.23	2.03	2.20 Ni	96.59	0.0228	0.0205
	No. 62		A1-F9	0.45	5.64	4.32	56.3		2.39	1.78	4.98 Ni	93.89	0.0531	0.0424

Analyses of 25-Day Bayonne Rusts—Table V:

Comparison of Tables III and IV show that in general the sulfate content of the outer loose rust increased with time. Hence, it was felt that analyses of early rusts might be instructive. It was conceivable that the inflection point in Fig. 4(*e*) might be changed. Accordingly a

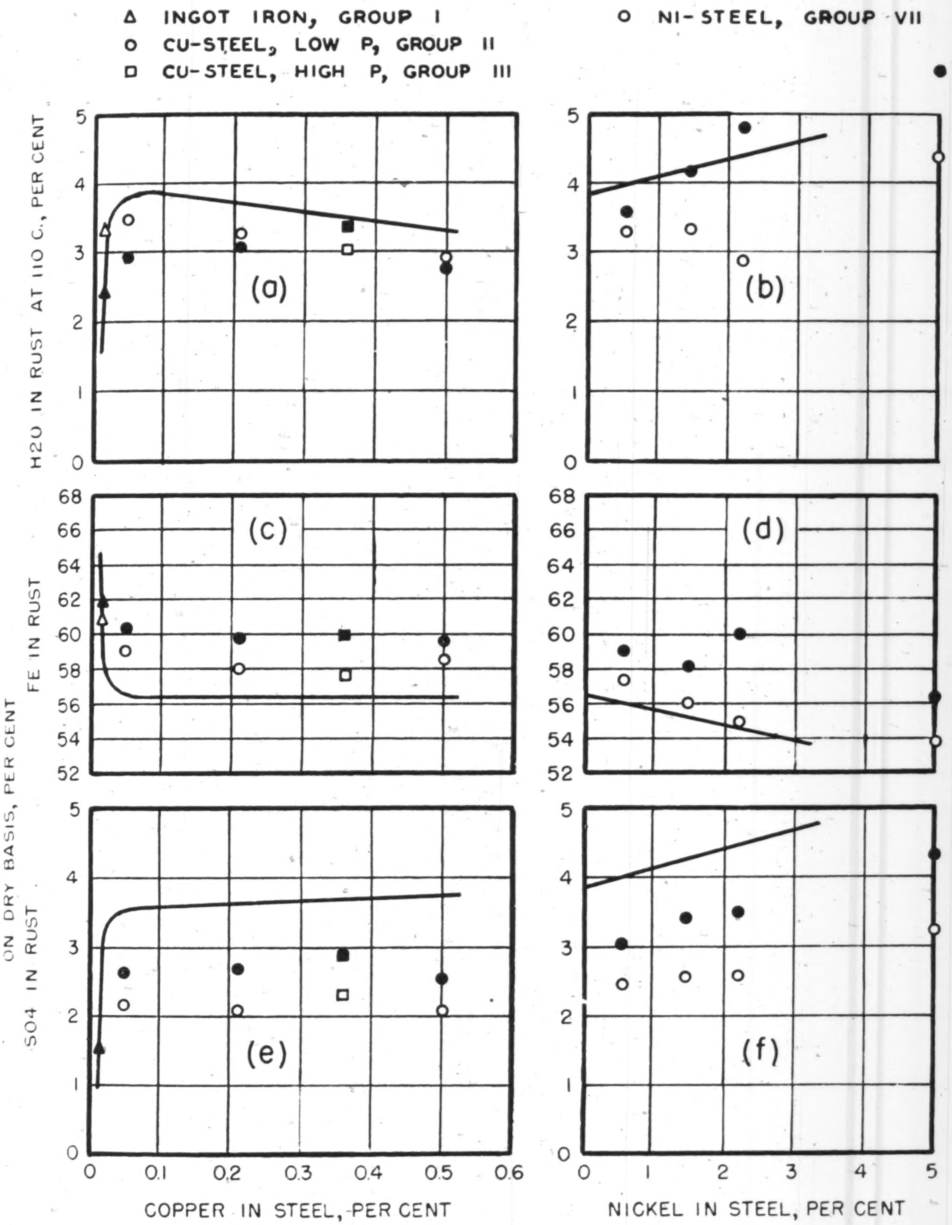


FIG. 7.—Percentage H_2O, Iron, and SO_4 in Loose 25-day Bayonne Rusts.
Solid Lines are from Fig. 4.
Open Points Represent Loose Rust from Skyward Surface.
Black Points Represent Loose Rust from Groundward Surface.

few steels were exposed and the rust crop collected after 25 days.

It was found that the amount of loose rust on the specimens was greater at 25 days than at 3 yr. At 25 days the loose rust made up a sizeable portion of the total rust. The total rust was almost twice the weight loss so that little rust had been lost.

The analyses are given in Table V and the moisture, iron, and sulfate contents are plotted in Fig. 7. The analyses failed to change the inflection for the copper steels. In general they support previous conclusions. They confirm that the sulfate content increases with time, although steel No. 44 is an exception, and show that the iron content decreases with time. These changes plus the changes in moisture, copper, and nickel do not exactly balance. At 25 days the analyses account for 67 to 73 per cent of the loose groundward rust, whereas at 3 yr. they account for 61 to 63 per cent.

The analyses confirm that there is more sulfate in the rust from the groundward surfaces than from the skyward surface. It is curious that the groundward rust also contains more iron and in the case of the nickel steels more moisture and more nickel. The reason for the higher iron content is not understood.

Included in Fig. 6 is a plot of the sulfate content of the loose groundward rust against weight loss. There was very little difference in the weight losses (Table V). As expected, the corrosion-resistant steels contained the most sulfate. The corrosion rate of steel No. 44 remained practically constant through 3 yr., but the corrosion rates of the other steels dropped off.

WEATHER EFFECTS

The 1941 series of tests brought out certain weather effects which are intimately connected with the proposed mechanism of rusting. These effects concern edge corrosion and weight losses, both of which varied with the exposure period. These effects are described below and then analyzed in relation to weather data.

Edge Corrosion:

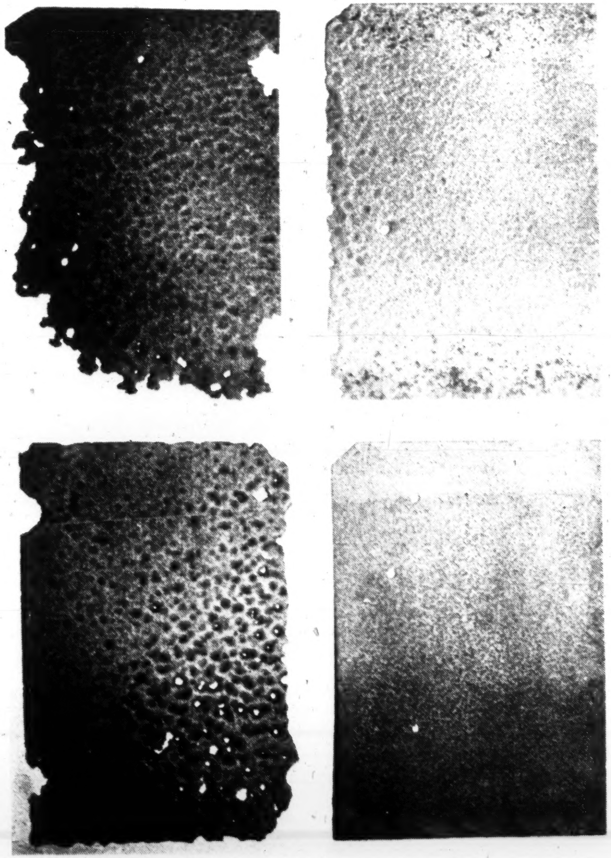
At Block Island, corrosion was more severe near certain edges than at other areas on the specimens. The attack was always worse at the left or western edge, at the bottom edge nearest the ground, and under insulators at the right edge.

Some typical examples are shown in Fig. 8. The appearance of steel No. 45 shows how severe this edge attack can be. This specimen was initially 0.072-in. thick and in places it was still 0.064-in. thick. Yet it was badly perforated near the susceptible edges. In the case of steel No. 54 the concentration of deep pits near the corroded edges is evident on the skyward surface. In the figure the groundward surface of steel No. 10 is shown, and again the pits are deeper and corrosion is more severe near the susceptible edges. Usually on the skyward surface the deepest pits were within 1 in. of the corroded edges, while on the groundward surface pits were still deep 2 or 3 in. from the corroded edges. Steel No. 20 is included in the figure by way of comparison. Steel No. 20 was quite resistant to corrosion, and as yet shows no noticeable edge attack. Its pits were smaller and more evenly distributed. In general edge attack decreased as the steels became more corrosion resistant, but this may be simply a matter of weight loss.

No comparable edge attack occurred at Bayonne, but it may show up later. Edge attack has been known to occur in industrial and semi-rural locations (9). It can be concluded that edge attack was much more severe at the marine than at the industrial location.

At Block Island the severity of the

Steel No. 45, B5-K2 Steel No. 54, B6-J2



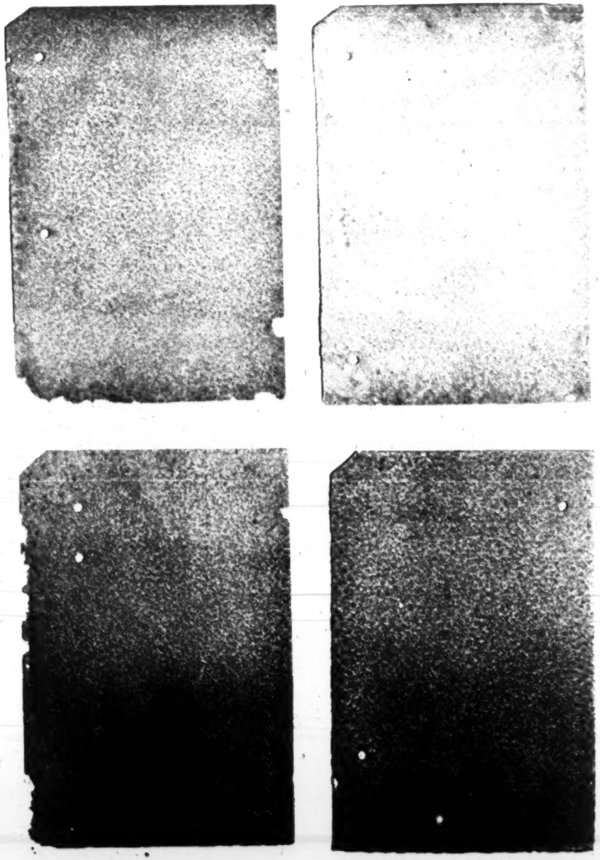
Steel No. 10, B1-P2 Steel No. 20, B3-E2

FIG. 8.—Typical Edge Effects at Block Island after 3 yr. Specimens have been Cleaned and have Two Drilled Holes for Identification. Specimen Size 4 by 6 in.

West

Exposed 405 Days, May 28, 1941 to July 7, 1942

Steel No. 5, B1-J1 Steel No. 10, B1-P1



East

Steel No. 5, B2-D2 Steel No. 10, B9-M1

Exposed 419 Days, July 8, 1942 to August 31, 1943

FIG. 9.—Influence of Exposure Period on Edge Effects; Skyward Surface. Specimens have been Cleaned and have Two Drilled Holes for Identification Purposes. Specimen Size 4 by 6 in.

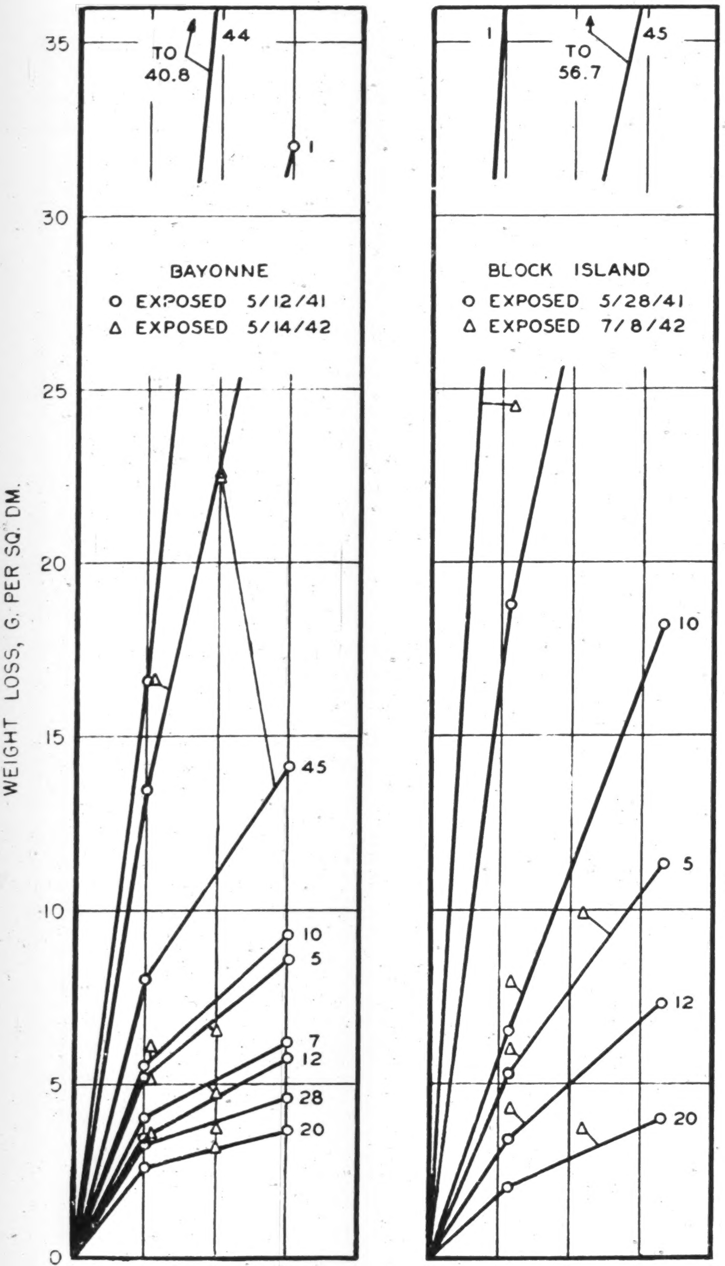


FIG. 10.—Weight Loss-Time Curves Showing Effect of Exposure Date.

edge corrosion varied with exposure period. This is shown in Fig. 9. During the period May 28, 1941 to July 7, 1942 the western edge suffered less corrosion and the eastern edge more corrosion than during the period July 8, 1942 to August 31, 1943. In the past there has been no adequate explanation of edge corrosion (**9**).

Effect of Exposure Period on Weight Loss:

Specimens of a few steels were put out in 1942 about a year after the main exposure. Some of these have been taken in after 1 and 2 yr. of exposure. The 1- and 2-yr. weight losses are plotted in Fig. 10 along with the weight loss time curves for the identical steels in the main exposure.

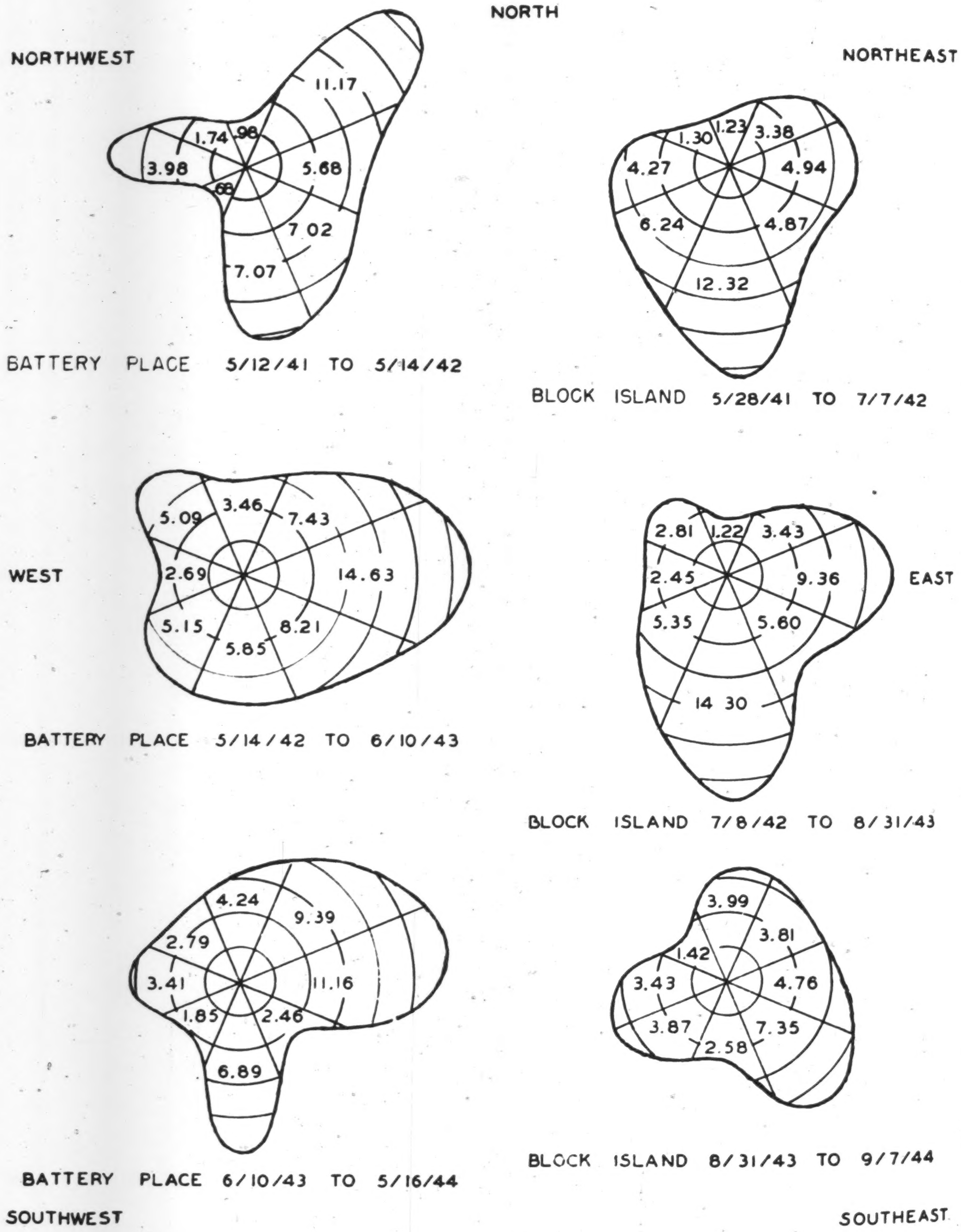
At Bayonne as compared with the first year May 12, 1941 to May 14, 1942 conditions were slightly more corrosive during the second year (May 14, 1942 to June 10, 1943). During the third year (June 10, 1943 to May 16, 1944) conditions were slightly less corrosive to the more corrosion-resistant steels (Nos. 5, 7, 28, and probably 20) but more corrosive to the fast corroding steels (Nos. 44 and 45). At Block Island as compared with the first year (May 28, 1941 to July 8, 1942) conditions during the second year (July 8, 1942 to August 31, 1943) were slightly more corrosive to steels Nos. 12, 5, 10, but less corrosive to steel No. 1. During the third year (August 31, 1943 to September 8, 1944) conditions were somewhat more corrosive to steels Nos. 5 and 20, and much more corrosive to steel No. 45. The fast corroding steels were more affected by weather conditions.

TABLE VI.—WEATHER DATA.

		Battery Place, N. Y.			Block Island, R. I.		
		5-12-41 to 5-14-42	5-14-42 to 6-10-43	6-10-43 to 5-16-44	5-28-41 to 7-7-42	7-8-24 to 8-31-43	8-31-43 to 9-7-44
		367 days	392 days	341 days	405 days	419 days	374 days
Normal rainfall, in.		43.20	45.88	40.47	45.00	47.35	42.05
Actual rainfall	inches	38.32	52.51	42.19	38.55	44.52	31.21
	per cent of normal	88.7	114.4	104.2	85.7	94.1	74.3
Actual rainfall with prevailing wind from the directions indicated, in.	NE	11.17	7.43	9.39	3.38	3.43	3.81
	E	5.68	14.63	11.16	4.94	9.36	4.76
	SE	7.02	8.21	2.46	4.87	5.60	7.35
	S	7.07	5.85	6.89	12.32	14.30	2.58
	SW	0.68	5.15	1.85	6.24	5.35	3.87
	W	3.98	2.69	3.41	4.27	2.45	3.43
	NW	1.74	5.09	2.79	1.30	2.81	1.42
	N	0.98	3.46	4.24	1.23	1.22	3.99
Rain from easterly semicircle, per cent		76.8	66.5	69.0	52.8	59.2	63.2
Days with more than 0.01 in. rain	days	97	156	99	125	142	113
	per cent	26.4	39.8	29.0	30.9	33.8	30.3
Days with light fog	days	88	152	122	157	219	197
	per cent	24.0	38.8	35.8	38.8	52.2	52.8

Weather Data:

It seems axiomatic that the variations in weight losses and edge effects with exposure period are related to the weather. For this reason the weather data for Battery Place, N. Y. (the nearest station to Bayonne) and for Block Island were collected. The summarized data are presented in Table VI. The difference between the two locations is surprising.



BATTERY PLACE 5/12/41 TO 5/14/42

BLOCK ISLAND 5/28/41 TO 7/7/42

BATTERY PLACE 5/14/42 TO 6/10/43

BLOCK ISLAND 7/8/42 TO 8/31/43

BATTERY PLACE 6/10/43 TO 5/16/44

BLOCK ISLAND 8/31/43 TO 9/7/44

FIG. 11.—Rainfall in Inches which Fell when the Prevailing Wind was from each of the Eight Directions Indicated.

While some limited attempts at correlating weather with rusting of steel have been published (**7**, **13**), the correlation has not been good. It seems likely that the reason is that while moisture must be present for corrosion to occur, actual rainfall washes away soluble material and is beneficial. Thus rain has a dual rôle, and it may affect different steels differently depending upon the amount of soluble material in the rust. Dew, fog, and high humidity would be expected to be harmful. Since weather cycles are varied and complex any exact correlation would require extensive data.

Weather Data and Edge Corrosion:

If rain washes away soluble material, such material might be expected to be more concentrated at the lower groundward edges than elsewhere on the specimens. Also if more rain came from the east than from the west, soluble material might be expected to be concentrated at the western edge of the specimens. For this reason the variation in rainfall with wind direction is given in Table VI, that is, the rain that fell when the prevailing wind was from each of 8 compass directions has been totaled for each yearly period. Thus, if during a given day 1.5 in. of rain fell and if during that day the prevailing wind was from the southeast, then the 1.5 in. of rain was credited as coming from a southeasterly direction.

The results are shown graphically in Fig. 11 using polar coordinates. The total area of the odd-shaped figures represents the total rainfall during the respective periods. The area between 2 radii represents the portion of the rainfall that fell when the prevailing wind was from the direction indicated. Thus at Block Island, during the period from July 8, 1942 to August 31, 1943, 9.36 in. of rain fell while the prevailing wind was from the east, so 9.36 has been plotted as the area of the easterly sector.

inches of rain = area of sector =

$$\frac{\pi r^2 \theta}{360} = \frac{45\ \pi r^2}{360} = 0.393\, r^2 \ldots\ldots (1)$$

In Fig. 11 the calculated radii have been smoothed out with wind direction to form continuous boundaries for the figures. The yearly variations are marked.

There is no doubt that at both Bayonne and Block Island much more rain came from easterly directions than from westerly. That the edge effects have been noticed at Block Island and not at Bayonne points to the chlorides in the marine air as being particularly effective in producing this type of attack. The insulators at the eastern edge prevent easterly rains from washing away soluble salts at these spots. On one specimen there was a band of perforations which fanned out from the upper right insulator toward the lower left corner. Corrosion was more severe everywhere that the salts collected.

At Block Island the predominance of rain from the east was greater during the second period than during the first. This explains the variation in edge effects with exposure period as shown in Fig. 9. During the second period more rain from the east was more effective in washing soluble salts out from under the eastern insulators so that corrosion was less there. At the same time more salts were concentrated at the western edge so that corrosion was increased at this edge.

Weather Data and Weight Losses:

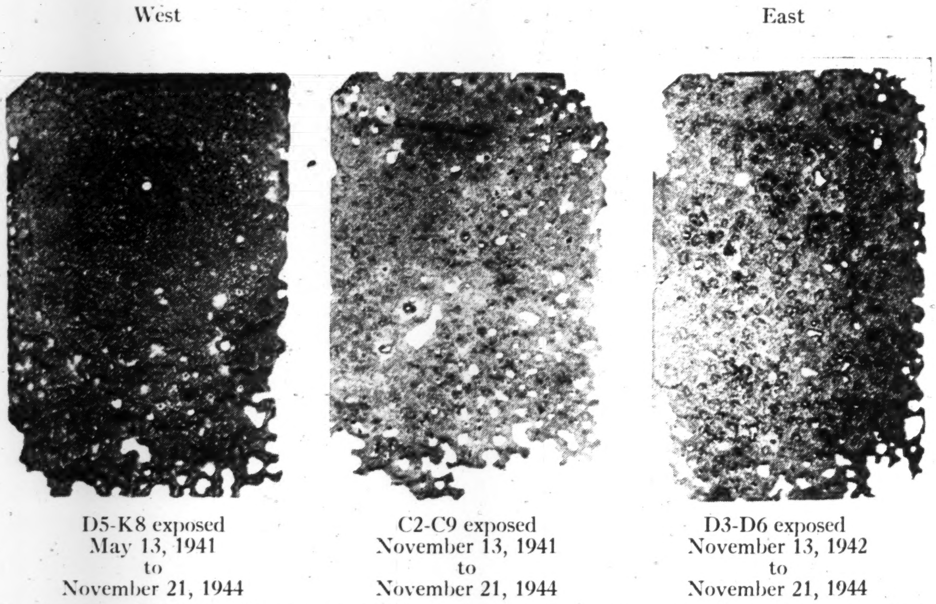
The correlation between weather data and weight losses is not so good as between weather data and edge corrosion, but nevertheless certain relationships are evident. Thus at Block Island during the third period there was as much fog and almost as many wet days as during the second period but much less rainfall. The result was harmful to all steels, especially to steel No. 45. The tendency for variations in the weather to affect different steels differently is believed to be tied in with the amount of soluble material in the rust.

Exposure Tests at Kure Beach, N. C.:

The author has had the opportunity of following some atmospheric corrosion tests on low-alloy steels being conducted at Kure Beach, N. C., a marine location (**14**). These tests are similar to those described in this paper. Some of these specimens have shown edge corrosion similar to that observed at Block Island. Three examples are shown in Fig. 12. The difference is that at Kure Beach corrosion has been more severe at the eastern edge.

This provided an excellent opportunity for checking the importance of wind direction during rainstorms. Weather data were obtained from Wilmington, N. C., which is near the exposure station. It was found that as compared with the more northern exposure sites Wilmington gets lots of rain from the southwest. During the $3\frac{1}{2}$-yr. exposure period, 46.6 per cent of the total rainfall occurred when the wind was from easterly directions; during the 3-yr. period 48.9 per cent; and during the 2-yr. period 45.3 per cent (compare Fig. 12). This compares with a 3-yr. average at Block Island of 58.5 per cent. Thus the corrosion at opposite edges at the two locations is in agreement with the theory.

Of course wind direction and rainfall vary, and at Kure Beach the variations have been marked. Thus from November 13, 1942 to November 13, 1943, 32.3 per cent of the total rainfall occurred when the wind was from easterly directions, and from November 13, 1943 to November 21, 1944, 56.5 per cent. Some specimens at Kure Beach have perforated first in the middle part of the specimen.



D5-K8 exposed
May 13, 1941
to
November 21, 1944

C2-C9 exposed
November 13, 1941
to
November 21, 1944

D3-D6 exposed
November 13, 1942
to
November 21, 1944

FIG. 12.—Typical Edge Effects on Steel No. 45 at Kure Beach, N. C. (**14**). Specimens have been Cleaned and have Two Drilled Holes for Identification. Specimen Size 4 by 6 in. Skyward Surface.

These perforations were caused by deep pits on the groundward side. It may be that in such cases soluble salts on the groundward surface have become concentrated in the middle portion of the specimen.

At Kure Beach the corrosiveness of the atmosphere with respect to steel has increased with time. This is shown in Fig. 13 by the weight loss data for steels Nos. 20 and 45. In the case of steel No. 20 specimens exposed at the same time have shown a decrease in corrosion rate with time, but specimens exposed at later dates have corroded faster. In the case of steel No. 45 this effect is more pronounced and corrosion rates have actually increased with time.

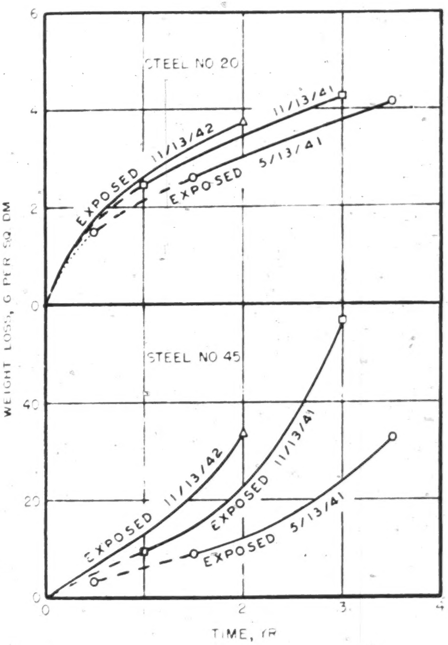


Fig. 13.—Weight Loss Time Curves, Steels Nos. 20 and 45 at Kure Beach

It is suggested that this effect is also due to wind direction on wet days. Wilmington is the nearest city to Kure Beach and is about 15 miles slightly west of due north. Since these tests were started in 1941 the amount of rain coming from the direction of Wilmington has been steadily increasing. This is shown in Table VII. The percentage of the total rain occurring when the wind was from the north increased from only 0.1 per cent early in 1941 to 12.8 per cent in 1944. It seems likely that the corrosiveness of the atmosphere at Kure Beach is connected with the drift of wet sulfur gases from Wilmington.

This makes it seem that the amount of sulfur dioxide in the air is particularly important at so-called marine locations. Table II showed the amount of sulfate to be considerable in the rust at Block Island, and it is known to be considerable in the rust at Kure Beach also. A comparison of weight losses of identical steels after 3.3 yr. at Block Island and 3.5 yr. at Kure Beach shows that the more corrosion-resistant steels have been corroding at nearly identical rates, but that the faster corroding steels have been corroding about one and a half times as fast at Block Island as at Kure Beach. Additional determinations of sulfur com-

TABLE VII.—WEATHER DATA AT WILMINGTON, N. C.

		5-13-41 to 11-13-41	11-13-41 to 11-13-42	11-13-42 to 11-13-43	11-13-43 to 11-21-44
		183 days	365 days	365 days	374 days
Normal rainfall, in		29.22	46.93	46.93	47.54
Actual rainfall	Inches	22.16	52.25	44.13	52.28
	Per cent of normal	75.8	111.3	94.1	110.0
Rainfall occurring with prevailing wind from the directions indicated, per cent	NE	10.9	13.6	17.2	28.7
	E	1.9	4.8	0.7	14.5
	SE	7.5	24.8	4.1	3.7
	S	27.8	22.4	17.2	7.6
	SW	47.2	25.4	45.3	19.9
	W	3.1	1.1	3.2	4.1
	NW	1.5	4.6	4.0	8.7
	N	0.1	3.3	8.3	12.8
Rain from easterly semicircle, per cent		31.2	55.4	32.3	56.5

pounds in the rust and in the air would be interesting.

MECHANISM OF RUSTING

The data presented throw much light on the mechanism of rusting. The corrosion rate is believed to be controlled by the quality and quantity of the water reaching the steel surface.

The quantity of water is not very great. An invisible film of moisture will support corrosion. On a 4 by 6-in. specimen a film of water of the same order of thickness as the adherent rust coating (Fig. 3) would weigh only about 4 g. As the rust becomes more protective the quantity of water reaching the steel surface would become less. It follows that only a few milligrams of soluble salts would make a big difference in the composition of the film of water.

In the literature it seems to have been tacitly assumed that in a given atmosphere each piece of steel is exposed to the same environment. Actually since corrosion products influence the amount of soluble salts, each steel is exposed to a separate environment. Since the corrosion products are determined partly by the composition of the steel, composition becomes of paramount importance.

Corrosion Reactions:

In a fictitious very pure air the corrosion reaction of pure iron would be as follows:

$$2\,Fe + a\,H_2O + 1\tfrac{1}{2}O_2 \rightarrow Fe_2O_3\cdot a\,H_2O \quad (x)$$

In a fictitious sulfurous atmosphere rain water could be regarded as dilute sulfuric acid and the corrosion reaction would be

$$2\,Fe + 3H_2SO_4 + 1\tfrac{1}{2}O_2 \rightarrow Fe_2(SO_4)_3 + 3\,H_2O \quad (y)$$

In an actual industrial atmosphere containing normal amounts of sulfur dioxide, the reaction would be a combination of x and y, and the corrosion product would be a basic iron sulfate.

$$2(x + y)Fe + 3yH_2SO_4 + 1\tfrac{1}{2}(x + y)O_2 + ax\,H_2O \rightarrow x\,Fe_2O_3\cdot y\,Fe_2(SO_4)_3\cdot ax\,H_2O + 3yH_2O \quad (z)$$

In the case of reaction x the corrosion product is insoluble, and presumably has no effect on the subsequent course of the reaction except as it blankets the iron and excludes water and oxygen. In the case of reaction y the corrosion product is soluble and would be expected to speed up the attack on the iron. It is well known that ferric salts are efficient cathodic depolarizers. In the case of reaction z the corrosion product is a basic sulfate. Its solubility might be expected to be somewhere between that of the hydroxide and the sulfate, or in other words to increase as the ratio of y to x increases.

It should be noted that under the conditions of reaction z the solvent is not pure water but water acidified with sulfur dioxide. At Bayonne the pH of rain water in the troughs of some special roofing specimens (12) was found to be as low as 4.1.

The occurrence of soluble salts has been well attested to in the literature, where white deposits on the drainage areas of samples have been repeatedly observed (7). At Bayonne the presence of soluble salts in the voluminous rust on steel No. 44 was demonstrated by extracting the rust with distilled water and detecting sulfate ion in the extract.

In the presence of alloying elements such as copper and nickel, the corrosion product is no longer a simple basic iron sulfate, but becomes a complex basic sulfate of iron, copper, and nickel. The solubility of this complex is apparently less than that of the relatively simple basic iron sulfate, and this is believed to be the deciding factor.

Porosity of Rust:

Rain water would be expected to wash away soluble corrosion products. In a sense this is beneficial, but it results in the rust having a porous structure. The more soluble the corrosion product the more porous the rust structure and the less protective the rust coating.

The variation in porosity of the rust coatings was demonstrated in the case of some fresh 24-day old rusts. On a dry sunny day drops of water were placed on the steel specimens. In the case of steel No. 1, which corrodes rapidly, the drop spread rapidly forming an oval 2 in. wide and 3 in. long. In the case of steel No. 12, which corrodes slowly, the drop ran rapidly down the specimen and collected at the bottom edge, with only a little spreading of perhaps $\frac{3}{4}$ in. In the case of steels Nos. 5 and 10, which corrode at intermediate rates, the drop started to run down but never reached the bottom edge. It spread to a width of perhaps $1\frac{1}{4}$ in. The drop dried fastest on steel No. 1 and slowest on steel No. 12.

As time goes on the rust becomes more protective. This is because the pores in the rust gradually become plugged with additional corrosion product. But the rate of plugging still depends on the solubility of the corrosion product. On 3-yr. old rusts the drops of water were much slower in spreading than on the 24-day rusts. On the most corrosion-resistant steels the drop tended to remain in place; it did not drain down the specimen and spread to only a limited extent. On faster corroding steels, the drops spread to a greater extent and sometimes ran down a few inches.

It may be that the color of the rust is determined to a considerable extent by its porosity. Generally powdering colored materials makes them appear lighter. Thus the more porous rust on the fast corroding steels is lighter in color. As the pores become plugged the rust color darkens. It has been postulated before that the color of rust depends on the size of the individual crystal (**15**).

Quality and Quantity of Water:

Coming back to the hypothesis that the corrosion rate of steel is determined by the quality and quantity of the water reaching its surface, it should be clear how the corrosion products determine both these factors. Initially when the surface is bare all steels are exposed to the same environment and corrode at about the same rate. This has been observed many times (**16**, **17**, **18**) and is supported by the data in Table V. As the corrosion products accumulate the amount of water reaching the steel surface becomes less. The solubility of the corrosion products then comes into play. Relatively insoluble products decrease the amount of soluble constituents in the water and thereby decrease corrosion. Relatively insoluble products do not wash away and thereby they decrease the porosity of the rust coating and decrease the quantity of water reaching the steel. Thus, as time goes on and the rust coatings become more protective, the position of the alloy steels improves.

Role of Sulfur Dioxide:

The importance of sulfates has been emphasized. This is because sulfur dioxide in the atmosphere is known to accelerate rusting. Rusting is quite slow in clean rural air. The need for increased corrosion resistance is not great (**19**). Nor is the benefit gained by alloying very marked (**20**). Corrosion is primarily by reaction x, and alloying cannot render the corrosion products any more insoluble.

In industrial atmospheres rusting is rapid due to contamination of the atmosphere with sulfur dioxide. Corrosion is by reaction z, and alloying elements which form complex insoluble basic sulfates are beneficial. The corrosivity of the atmosphere increases with sulfur dioxide content; the need for alloying increases with the degree of atmospheric pollution. However, when pollution becomes extreme the low alloy steels are no better than mild steel. This has been observed in smoke jacks of roundhouses (**20**) and in Doves Hole Tunnel (**21**). Presumably the ratio of y to x in equation z becomes so high that the basic sulfates are fairly soluble.

Role of Chlorides:

At marine locations chlorides become important. But the data from Kure Beach and Block Island suggest that a combination of sulfur dioxide and chlorides may be particularly damaging. Probably the amount of salt is not so important as the amount of iron chloride which may be formed in the rust coating. An acid reaction due to sulfur dioxide would be expected to facilitate the formation of ferric chloride. Placing the emphasis on ferric chloride would explain the observation that specimens exposed to a relatively mild industrial atmosphere and drenched with a 10 per cent solution of common salt once a week lost more weight than duplicate specimens which were similarly drenched once a day (**22**).

The reactions involving ferric chloride and basic ferric chloride are probably similar to reactions (y) and (z), but the chlorides are more soluble and wash away more readily. This explains the small amount of chlorides found in the rust at Block Island. The solubility of the chlorides would be expected to make it more difficult to plug pores in the rust coating. Corrosion rates have been decreasing much more slowly at Block Island than at Bayonne.

Chlorides are probably more corrosive than sulfates, making even small amounts important. Electrolytic iron from a chloride bath corroded more rapidly in the atmosphere than electrolytic iron from a sulfate bath, the difference being attributed to residual traces of chlorides (**6**). The edge effects at Block Island and Kure Beach attest to the corrosivity of chlorides.

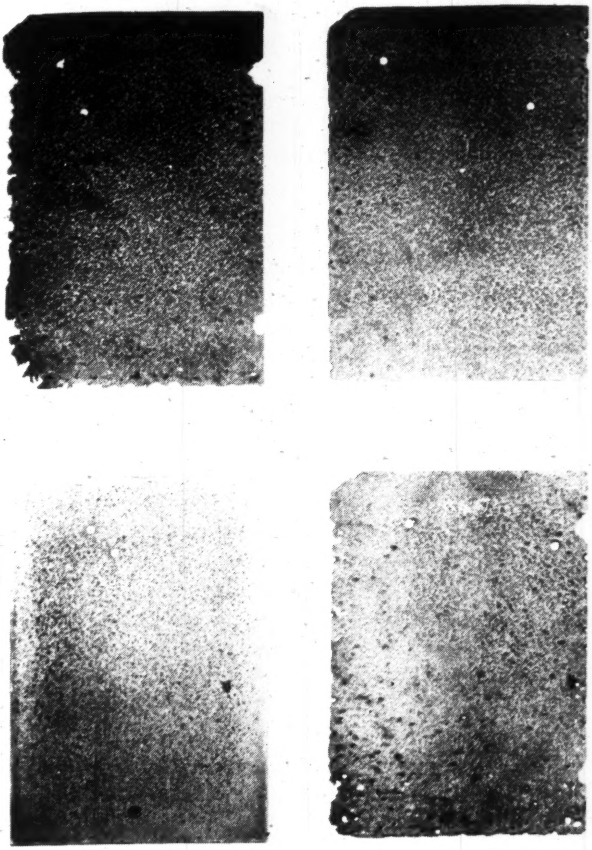
An attempt was made to show that chlorides had concentrated at the edges of the Block Island specimens. Rust was removed from corroded edges. To obtain a big enough sample, the 3-yr. old rusts from steels Nos. 1, 10, 11, and 54 were combined. In each case for comparison an equal weight of rust was removed from the skyward surfaces remote from the edges. Analyses showed 0.03 per cent chlorides in the combined rust from the skyward surfaces and 0.04 per cent chlorides in the rust from the edges. This is in the right direction, and the figure for the corroded edges is low, because this rust sample was contaminated with small pieces of frayed steel.

A composite 3-yr. rust sample from nickel steels Nos. 28, 147, 46, 35, and 20 at Block Island was analyzed and 3.69 per cent water and 0.04 per cent chloride was found. The chloride was lower than expected. These nickel steels are comparatively corrosion resistant (Fig. 3). It may be that alloying elements which remove sulfur dioxide from the field of reaction by forming complex basic sulfates, prevent the formation of much ferric chloride.

Role of Alloying Elements:

In the absence of data it cannot be certain that the proposed mechanism applies to other than copper and nickel steels. However, it seems significant that with the exception of phosphorus, all helpful elements, such as chromium and manganese, form insoluble basic salts, and that all neutral elements, such as carbon and silicon, do not.

When several elements are added at the same time, results are unpredictable, and it may be that the proposed mechanism does not tell the whole story. Thus silicon which is not beneficial by itself is helpful in combination with chromium, copper, and phosphorus.



B2-D3
Bare
31.3 g. loss

B2-D8
20 millionth in. Nickel
48 hr. Anneal
18.4 g. loss

B3-C4
100 millionth in. Nickel
48 hr. Anneal
8.9 g. loss

B3-C9
100 millionth in. Copper
48-hr. Anneal
32.7 g. loss

FIG. 14.—Effect of Nickel and Copper Coatings on Corrosion of Steel No. 5, Exposed at Block Island from July 8, 1942 to September 7, 1944. (**24**).

It also seems significant that the only harmful element in steel from an atmospheric corrosion standpoint is sulfur. Upon corrosion this would form sulfates and act in the same manner as atmospheric sulfur dioxide. Copper additions to steel have been regarded as fixing the sulfur by forming copper sulfide. In a sense this may be true but copper sulfide would oxidize in the atmosphere and the ultimate corrosion product would be a basic sulfate. In all the steels of the present tests the sulfur content was low enough to have no noticeable effect.

Going through the periodic table does not suggest any better alloy additions. Elements forming insoluble sulfates are not soluble in steel, although the presence of 0.06 per cent lead has been said to be beneficial (23). Most elements which are known to form insoluble basic sulfates have already been tried. The exceptions are the precious metals, particularly rhodium and palladium.

Other Mechanisms:

Carius (5) has suggested that in copper steels corrosion resistance is increased by the formation of a copper or copper-rich layer next to the steel surface. It has already been pointed out that analyses of rust coatings failed to show any real concentration of copper in the outer loose rust or in the adherent rust. After removing the rust by cathodic treatment in hot copper-free 10 per cent sulfuric acid, no metallic copper is ever seen on the metal surface. Thus there seems to be no support for the theory of Carius.

In some separate tests initiated by Wesley (24) thin electrodeposited copper coatings on steel No. 5 were actually found to be harmful. This is shown in Fig. 14 where the copper-coated specimen is profusely perforated. On the other hand, thin nickel coatings were beneficial provided they were given a diffusion anneal sufficient to produce a small amount of nickel-iron alloy. The conclusion seems to be that thin coatings of pure copper or nickel are harmful, but that alloy coatings are helpful. The alloy corrodes and introduces beneficial corrosion products into the rust. Heat-treated nickel coatings are better than heat-treated copper coatings because nickel is more soluble in steel.

It has been proposed that variation in corrosion is due to length of time wet, the rust on poor steels being more hygroscopic. After 1 yr. at Block Island corrosion rates varied from 165 to 4.3 milligrams per sq. cm. per day or 40 to 1. It would be impossible for one steel to be wet 40 times longer than another (Table VI). Nevertheless all steels may not be wet the same length of time. The thick rust on the fast corroding steels is definitely slower in drying out.

Other ideas that have been expressed are that the steels have different critical corrosion humidities, that the low-alloy solid solutions are more noble, that alloying decreases the potential difference between the metal and the rust. One trouble with these ideas is that they should affect corrosion from the start, whereas it takes time for atmospheric corrosion rates to begin to diverge. The time effect explains why it has been difficult to devise accelerated tests (16).

It should be obvious why atmospheric corrosion of low-alloy steels does not parallel immersed corrosion (22). In immersed corrosion all steel specimens are exposed to the same environment.

CONCLUSIONS

1. Corrosion rate depends on the quality and quantity of water reaching the steel surface. The quality is affected by atmospheric pollution, by the solubility of corrosion products, and by the wash of rain. Quantity is affected by shelter and by porosity of the rust which in turn is affected by the solubility of corrosion products. The quantity reaching the steel surface at any one time is not very great so that even a few milligrams of soluble material makes a big difference in quality.

2. Function of copper and nickel is to render sulfates insoluble by forming complex basic sulfates. The percentage of sulfates in the rust increases as weight loss decreases.

3. Porosity of rust decreases with time. Rust on corrosion-resistant steels is least porous.

4. When several elements are added at the same time, results are unpredictable and it may be that proposed mechanism does not tell the whole story.

5. Going through the periodic table with the new mechanism in mind does not suggest any better alloy additions.

6. Edge effects at Block Island were due to soluble chlorides being swept to corroded edges by the wash of rain.

7. Variation in weather affects corrosion, but may affect different steels differently. This is because rainfall has a dual rôle. Moisture must be present for steel to corrode, but washing away of soluble material is beneficial. Dew, fog, high humidity, and shelter would be expected to be harmful.

Acknowledgments:

The author wishes to express his appreciation to W. A. Wesley and F. L. La Que for permission to include some of their experimental data.

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DISCUSSION

Mr. H. E. Smith[1] *(by letter)*.—The black sheet tests sponsored by the Society's Committee A-5 on Corrosion of Iron and Steel, at Annapolis, now approaching 30 yr. exposure, confirm one observation in the text of the paper. The rust on the more rapidly corroded sheets is lighter in color, more porous and friable, and less tightly adherent to the sheets. This was especially true during the first years of the exposure. The differences are not now so striking, possibly due to adhesion of miscellaneous dust and dirt, and perhaps to plugging of pores mentioned in the paper. This latter is especially notable on the lead-coated wires exposed by Committee A-5 at various locations.

With reference to the third paragraph of the synopsis of the paper, the more severe corrosion near certain edges of the specimens is also illustrated in the Annapolis tests, where nearly all of the failures (perforations) have been within 12 in. of the lower ends of the sheets, which are 60 to 80 in. long and exposed in an inclined position.

The last paragraph of the synopsis mentions variations in composition and amount of corrosion products as producing a different environment for each specimen. This appears obvious, however, the differences are really intermediate causes and the result of the primary causes of composition and physical properties of the metal and atmosphere, taking the latter in the large sense. It includes not only the composition of the atmosphere, particularly with respect to definitely corrosive gases, but also temperature, wind and sunshine, affecting speed of drying after rain. Rain water, especially the first which falls, may vary in composition in different localities and at different times. And wind may carry particles of gritty dust which remove portions of protective films. However, all of this reduces to two primary causes, metal and atmosphere.

Mr. Walter Leaf[2] *(by letter)*.—Some data that I have collected during the past two years may be interesting in connection with this paper.

My problem is the opposite of that of the author, in that I desire rust to form at the greatest rate possible. We have a water supply with 5 grains of silica per gallon in solution, and I have found that freshly-formed hydrous oxide of iron absorbs the silica very strongly, the rust from 1 lb. of iron picking up about 1 lb. of silica. In my particular problem, I have found that if the water running to the iron shavings has more than about 2 grains of silica, a protective coating is formed on the iron, preventing further rusting, at a pH of around 6.8 or higher. But if I circulate water from the rusting tank, diluting the incoming water to less than two grains, rusting takes place rapidly at a pH as high as 7.6. Thus, there is an equilibrium which is upset one way or the other. If rusting is too slow for the amount of silica present, the silica is absorbed on the oxidized iron surface, giving a dense protective coating. If the rusting is a little more rapid, the silica is absorbed by oxide in suspension before reaching the iron surface and no protective coating is formed. This fact might be of importance in corrosion, where silica dust might accumulate on the test specimens, go into solution and then be absorbed.

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[2] Research Technician, The Denver & Rio Grande Western Railroad Co., Denver, Colo.

We have built an experimental plant to treat 1800 gal. of water per hour and have an 8 by 8-ft. wood stave tank filled with steel lathe turnings, through which the water flows, with an aerating system in the bottom. At times, it is quite a problem, trying to get rust to form. Without any circulation or pretreatment to lower the pH, water will run over this tremendous iron surface without a trace of rust forming, and come through as sparkling clear as it entered, even with very heavy air agitation. On the other hand, with circulation and carbonation to pH below 7.4, the water has so much rust that light transmission through it is limited to several inches.

MR. MARC DARRIN[3] (*by letter*).—The corrosion reactions given on page 574 may be somewhat over-simplified. They disregard the mechanism and location at which atmospheric sulfur may be oxidized from the sulfurous to the sulfuric state, nor do they indicate whether some of the iron may remain in the ferrous state. Although most of the iron is ferric, probably some remains as a hydrous ferrous - ferric compound.[4] Presumably atmospheric sulfur dioxide dissolves in moisture on the panel and combines with some of the hydrous iron oxides to form ferrous sulfites (or hydrosulfites) and sulfates which are oxidized by atmospheric oxygen to basic ferric sulfates.

It is felt that conclusion 7 regarding effect of weather (and presumably temperature) should be a part or continuation of conclusion 1, namely, the factors which influence the rate of corrosion.

The theory postulated on page 559 (and embodied in conclusion 2) is not very convincingly supported by the author's data, although probably in line with it, namely, that the "function of the copper and nickel is to render sulfates insoluble by forming complex basic sulfates." The mechanism may not be this simple. Possibly it is not so much the greater insolubility of the copper and nickel sulfates as their greater resistance to hydrolysis. For instance ferric sulfates may hydrolyze during a wet period, liberating acid which dissolves additional iron. If the author's theories are correct, the more soluble sulfate from the rusting of a very low-copper steel such as No. 44 should give a markedly lower SO_4 content in the rust on the skyward surface. Tables III and V show that this was not so.

MR. H. D. HOLLER[5] (*by letter*).—The results of the careful analytical work in this investigation furnish an excellent demonstration of the importance of the nature of the corrosion product in controlling atmospheric corrosion. While the lower rates of corrosion, attributable to the low solubility of basic sulfates may not be due to passivity in the usual sense, they do recall a paper presented in 1929 by McCulloch at the Pittsburgh meeting of the American Electrochemical Society, in which he showed that the passivity of certain metals in sulfuric acid solutions may be due to the slow solubility of the sulfate film formed on the metallic surface. The relation between weight-loss and amount of sulfate in the corrosion-product as shown in Fig. 6 certainly tends to support a similar conclusion, even though the conditions of testing were entirely different.

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[3] Chief Research Chemist, Research and Development Dept., Mutual Chemical Company of America, Baltimore, Md.

[4] O. Bauer, "Korrosion Metallischer Werkstoffe," Vol. I, p. 264, Edwards Bros., Ann Arbor, Mich., 1943.

[5] Chemical and Metallurgical Dept., Westinghouse Electric Corp., East Pittsburgh, Pa.

It is apparent from this investigation that a better definition of the conditions of test than the geographical location is badly needed. It certainly is not sufficient to say that the conditions were "industrial," or "marine." The consumer faces a similar problem in defining the conditions of service for which he must select a material. His difficulty is great enough without having to forecast the weather also.

The correlation of weather conditions with the results of atmospheric exposure tests has been advanced by this investigation; and a plausible explanation of results has been offered. However, the data in Fig. 13 showing that corrosion rates depend upon the particular year of exposure illustrate the need of better methods of defining conditions. What we need is a unit of corrosivity so that weight-losses or other losses may be plotted, not against time, but against units-of-corrosivity multiplied by time. Perhaps more complete records of atmospheric conditions, such as those initiated in this investigation will lead to a more exact definition of corrosivity.

This paper is a very positive contribution toward that end.

MR. M. A. COMLEY[6] (*by letter*).—The paper breaks new ground, since it covers a theory of outdoor corrosion of steels during long periods of exposure rather than during the initial stages of corrosion which have already received much study. Commercial interest lies chiefly in the relative corrosion rates after long exposure, and since the value of nickel or copper additions only gradually develops, an explanation of the long-term effect of these additions is especially welcome.

A considerable volume of evidence in regard to the composition of rust in relation to the composition of the steels, their periods of exposure, the rainfall, and the wind direction is collected in this paper. This provides a sound experimental basis on which is founded the theory that the relative rates of corrosion are dependent on the quality and quantity of water reaching the metal surface. This is considered to be mainly controlled by the porosity of the scale. In steels containing nickel or copper, the pores in the scale are gradually blocked by insoluble duplex basic sulfates of nickel, copper and iron. The theory is in general accordance with (*a*) the results of numerous analyses of the corrosion products of steels, contained in the paper, (*b*) analyses of nickel and copper corrosion products contained in earlier work, and (*c*) the assumption that rusting substantially takes place under moist conditions.

If it is granted that rusting takes place by an electrolytic mechanism rather than by dry ionic combination (and there is considerable evidence in the literature in favor of this view) the new ground covered is mainly included in the postulate that nickel and copper additions form with iron insoluble complex basic sulfates or chlorides which render the coating on the alloy steels increasingly impervious to moisture. This accounts satisfactorily for the fact that the value of these additions only develops gradually. The action is analogous to the effect of a deposited film of calcium and zinc carbonates in restraining the corrosion of zinc exposed to hard water.

Accumulation of corrosion products only partially removed by rain may accelerate the corrosion of certain metals in humid or saline atmospheres.[7] The theory in this case asserts that a relatively small amount of nickel or copper salts builds up a coating which not only does not accelerate corrosion, but in time actually reduces it.

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[6] Research and Development Dept., The Mond Nickel Company Limited, England.

[7] Schikorr, Elektrochemische Zeitschrift, Vol. 43, p. 697, (1937).

The theory is useful in suggesting that the number of effective addition elements is limited, and that the relative rates of corrosion of mild and alloy steels are controlled by the corrosion product rather than by traces of addition elements left on the metal surface.

The experimental results are open to very little, if any criticism, but there are a number of theoretical points which are worth consideration. It is stated on the first page of the paper that "A factor which has been neglected in the literature is the composition of the film of electrolyte on the steel surface. It has been tacitly assumed that in a given atmosphere each test specimen of steel is exposed to the same environment."

We would suggest that other workers, even when they referred to exposures carried out in the same environment, did in fact realize that the conditions at the metal surface were dependent on the adherent corrosion product and retained electrolyte, even if their effect on the metal was not specifically mentioned.

Vernon[8] and Hudson,[9] for example, have referred to the type of rust or corrosion product formed, and to its contained electrolyte, and have treated the metal and adherent (soluble or insoluble) corrosion product as a whole[10] following a procedure usual in dealing with wet corrosion, although it is true that relatively little attention has been paid to the soluble corrosion products of steels. In this connection the statement on page 578 of the paper that in immersed corrosion all steel specimens are exposed to the same environment also seems to require a little modification. Evans,[11] for example, has discussed the effect of the electrolyte contained in semipermeable rust coatings formed in saline solutions.

In the discussion on alternative corrosion mechanisms on page 578, there is a rejection of the idea of critical humidity, which Vernon essentially applied to the initial stages of atmospheric corrosion. It is very doubtful if he would extend his views on the effect of critical humidity and hygroscopicity to the extent of asserting that these were more than minor factors controlling the corrosion rates of alloy steels after long periods of exposure. Moreover since the initial corrosion products of mild and alloy steels must differ extremely little in composition, there seems no reason to anticipate, as suggested on page 578, that there should be significant differences in their critical humidity or hygroscopicity sufficient to bring about initial differences in their corrosion rates. As mentioned later, it is thought that hygroscopicity may be of some importance, but the theory of critical humidity hardly seems to compete with that outlined in the paper.

Vernon showed[12] that invisible oxide films can retard initial corrosion and that films of this type are formed by a dry reaction similar to the fictitious type formulated on page 574. The work of both Vernon[13] and Hudson[14] indicates that significant corrosion then proceeds by an electrochemical mechanism dependent on a moisture film. For example, pure air free from sulfur, even when super-saturated, will cause little corrosion. Traces of sulfur dioxide can initiate corrosion at a critical humidity, but the corrosion rates only become really serious when there is super-saturation, or when traces of electrolyte are retained by particles of dust on the surface.

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[8] Vernon, *Transactions*, Faraday Soc., Vol. 31, pp. 1668–1700, (1935).

[9] Hudson, *Transactions*, Faraday Soc., Vol. 25, p. 204 et seq., p. 251 (1929).

[10] Vernon, *Transactions*, Electrochemical Soc., Vol. 64, p. 316 (1933).

[11] Evans, *Journal*, Soc. Chemical Industry, Vol. 44, p. 168T.

Mears and Evans, *Transactions*, Faraday Soc., Vol. 31, p. 532 (1935).

[12] Vernon, Wormwell, and Nurse. *Journal*, Chemical Soc., (1939), pp. 621–632.

Vernon, *Transactions*, Faraday Soc., Vol. 23, p. 159 (1927); Vol. 31, p. 1670 (1935).

Also studies were made by Freundlich. (Zeitschrift für Physikalische Chemie, Vol. 128, p. 321).

[13] Vernon, *Transactions*, Electrochemical Soc., *loc. cit.*

[14] Hudson, *Transactions*, Faraday Soc., Vol. 25, p. 244 (1929).

The fact that iron corrodes at localized areas with the formation of pits, together with experimental results of the type outlined above, certainly points to an electrochemical mechanism. This is not brought out clearly in the paper, although there is little doubt that the author is in agreement with this view, and indeed he stresses the influence of the composition of the electrolyte. Nevertheless, implications of the theory seem at times to be ignored in the discussion of the corrosion reactions on page 574.

On page 575, a simple oxidation reaction x is considered to take place in rural air. Alloy steels show no significant difference from mild steel since under these conditions they form oxides and do not form insoluble sulfates. It is suggested that the similarity in behavior is not due to the fact that both mild and alloy steels undergo direct oxidation (Vernon's results limited direct oxidation in pure air to the formation of a very thin, nearly invisible film) and that they do in fact undergo electrolytic corrosion, which takes place just as in industrial air.

The corrosion products of copper and nickel in rural air and in marine air have been shown by Vernon and others[15] to contain sulfates (with and without chlorides and some carbonates) of increasing basicity dependent on the period of exposure. The Block Island rusts also contained sulfates. The presence of these salts infers that some electrolytic corrosion must have taken place. In these circumstances, the similarity of corrosion rates of different steels in rural air may be due to one of two reasons. Either (*a*) rusting is very slow (because only traces of sulfur are derived from the air and the steel), and the advantages of alloy additions may only be manifested after very prolonged exposure, or (*b*) if corrosion is slow, it would be possible for the soluble nickel or copper sulfates or chlorides to be washed away as fast as formed and before they could form a basic coating. In this case, alloying would never effect an improvement. The figures in Table III show that a large proportion of nickel and copper is actually lost from the rust coating.

It is thought that the following amplification or modification of the theory contained in the paper may conform rather more closely to certain of the experimental facts.

After breakdown of the original transparent oxide film, the first products of corrosion consist of sulfates and chlorides with a much lower proportion of carbonates, especially in industrial air. The iron salts are readily hydrolyzed directly to hydroxides and oxides giving rise to an electrolyte having an acid reaction, which promotes further corrosion. The more sulfurous the atmosphere the more hydrolysis is restrained, and the further from the metal surface deposition of hydroxide takes place. In any case a loose porous rust results.

Nickel or copper salts, however, hydrolyze at cathodic areas, or in contact with air, less completely than iron, and are thus converted to basic salts (within the iron oxide coating). It is also possible that a proportion of basic salts with some sulfides may be formed directly from nickel or copper and assist in the production of an impervious coating.

The figures in Table III show that an even greater proportion of nickel and copper than of iron was washed away from the surface of the steels, yet a small proportion of copper (about 0.03 per cent) and less than 0.2 per cent of nickel in the steel greatly reduced the corrosion rate. It is thought that the reduction may be due to these elements gradually forming, close to the metal surface, a coating of their basic salts which excluded sufficient moisture to enable a proportion of the iron to change to basic sulfate instead of hydrolyzing completely. The paper shows that in time the adherent layer of basic salts surpassed in quantity the loose rust. At this stage the results in Tables III and IV show that the sulfate content of the loose rust was roughly 3 to 4.5 per cent, the sulfate content of the adherent rust being perhaps a little lower.

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[15] Vernon, *Journal*, Chemical Soc. (1934), p. 1853.

The analyses show that the loose rust contained a very large excess of iron sulfate over the nickel or copper sulfates. It would be of considerable interest to obtain, if possible, similar analyses of the adherent rust, since the result for steel 7 (Table III) again shows a high sulfate-copper ratio. If this is generally true, the basic iron sulfate played a very important part in blocking the pores in the scale, and it may be questioned whether there is any need to postulate the formation of relatively insoluble complex basic sulfates of copper or nickel with iron, to account for increased corrosion resistance. A small proportion of basic nickel or copper sulfate may enable a larger proportion of iron to become basic and in this way to fill the majority of the voids in the porous oxide coating. The basic iron salts would be the main factor directly improving corrosion resistance. Higher, but nevertheless relatively small, proportions of nickel or copper might reasonably have little effect on the amount of basic iron sulfate formed, and would merely bring about a minor increase in corrosion resistance by further blocking the pores in the coating. This is in accordance with the relation between nickel and copper contents and weight losses shown in Fig. 3.

The views expressed in the paper that the porosity of the rust would affect the drying out time seems sound. It would also influence the minimum atmospheric humidity necessary to maintain corrosion. A thick porous rust might also retain hygroscopic acid electrolyte. The results show that the weight of loose porous rust on the corrodible steels was, in fact, much higher at all stages than on the relatively noncorrodible steels. Without questioning the major importance of the effect of basic salts, it remains possible that the moisture-retaining capacity is of distinctly greater importance than is suggested on page 578 of the paper.

The above considerations do not detract from the main thesis that the difference between the rates of corrosion of mild and alloy steels is due to their relative capacity to form a proportion of adherent protective rust, the protective action being due to the presence of basic sulfates or chlorides.

MR. W. H. J. VERNON[16] (*by letter*).—The paper by Mr. Copson is very much to be welcomed especially for the large amount of valuable data that it provides on the composition of the atmospheric corrosion product of ferrous materials. Systematic information of this kind is long overdue. In the case of nonferrous materials I made an attempt some years ago[17] to provide relevant data, and, in particular, to distinguish between the composition of the product left adhering to the metal and that carried away in soluble form by rain. Striking differences in behavior were revealed, according to the relative incidence of the two components that make up the total attack, the relationship being considerably affected by the nature of the early adherent product and the manner in which it provided a "membrane" to retain liquid in contact with the metal.[18]

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[16] Chemical Research Lab., Dept. of Scientific and Industrial Research, Teddington, England.

[17] *Transactions*, Faraday Soc., Vol. 19, p. 855 (1924); and Vol. 23, p. 166 (1927).

The author stresses that "owing to the influence of corrosion products each steel is exposed to a separate environment" and concludes that this factor has been neglected in the literature. Mr. Copson has certainly brought out the former point with great effectiveness and in so doing has performed a useful service. He will probably agree that the principle is very similar to that established in the earlier (non-ferrous) work. This work subsequently led to the study of the patina on copper, in which the development of the coordination compound $CuSO_4 \cdot 3\ Cu(OH)_2$ was shown.[19] The view has, I believe, been fairly widely held that the copper in copper-bearing steel plays an analogous rôle in leading to the formation of insoluble complexes in the product, but the evidence and discussion now advanced by Mr. Copson carry the whole matter very considerably further.

The study of the rôle of the corrosion product in the open-air corrosion of copper and its alloys had long encouraged me to feel that a similar study for ferrous materials would be well worth-while. Early in 1939 a modest start was made, in collaboration with Mr. E. G. Stroud (Chemical Research Lab., Teddington, England), using a series of irons and steels as used in the field tests of the Iron and Steel Institute Corrosion Committee. The technique was similar to that of the earlier work except that provision was made for distinguishing between the soluble and insoluble part of the product which leaves the specimen. The tests were brought to an end in 1940, but pressure of other problems has so far prevented publication of the results. Meanwhile, several features, in view of their bearing upon Mr. Copson's findings, may possibly be of interest.

1. The ratio of copper to iron in the *adherent rust* is considerably less than the values quoted by Mr. Copson: on the other hand, in the *insoluble detached rust* it is considerably higher, and higher still (higher than in the original metal) in the *soluble component.*

2. There is, throughout the series, wherever copper is present in the original steel in measurable amount, a tendency for the ratio to increase in the products in the order stated in (1).

3. The higher the copper content of the original steel, the lower, in general, is the (relative) copper-iron content of the product.

4. The ratio (in the product) is lower in tests started in the winter than in tests started in the summer.

5. The addition of 1 per cent chromium to the steel increases the copper-iron ratio in the product.

6. Total corrosion (measured by loss of weight of specimen) is rather greater in tests started in the winter.

The fact that in all Mr. Copson's experiments the copper-iron ratio is less for the product than for the original metal may find some elucidation in these results, since it is clear that in the early stages there is a preferential dissolving of copper as compared with iron. (The results are also consistent with results obtained in the work with copper[17] since it was found that in the early stages the principal product was normal copper sulfate which was freely removed by rain. Retention on the specimen surface was dependent on the formation of basic copper sulfate, the solubility of which decreases as the basicity increases with time.) Evidently it is the condition rather than the quantity of copper in the product that determines its protective effect. It seems probable that longer periods of exposures would lead to an increasing value (though at a falling rate) for the copper-iron ratio in the product, of which, indeed there already seems some indication in Mr. Copson's paper. Incidentally, one would like to ask the author what procedure he followed for removing rust from the specimens, especially in the case of short periods of exposure (for example 25 days at Bayonne).

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[18] *Transactions,* Faraday Soc., Vol. 23, p. 172 (1927).

[19] W. H. J. Vernon and L. Whitby, *Journal,* Inst. of Metals. Vol. 42, p. 181 (1929); and Vol. 44, p. 389 (1930).

A valuable feature of the paper is the graphical presentation of composition of rust in relation to copper content that has been permitted by the large amount of available data. It is not possible in this contribution adequately to discuss various other points that have been so usefully demonstrated, as for example the influence of the texture of the rust and the relationship with weather data. It is gratifying to note that the work is proceeding, and a further communication in due course will be awaited with the greatest interest.

MR. H. R. COPSON (*author's closure, by letter*).—I am grateful for the discussions which have been presented, particularly for the different points of view which have been expressed. Mr. Vernon's and Mr. Comley's comments are especially appreciated because they were made from a vantage point acquired by the British from extensive studies of the initial stages of atmospheric corrosion.

Mr. Comley and Mr. Darrin criticize the corrosion reactions on page 574 as being over-simplified, and they probably are justified in this. The reactions were included to illustrate the rôle of basic sulfates. As the discussors point out the reactions can be broken down into several steps. The author certainly agrees that rapid rusting of iron in the atmosphere proceeds by an electrochemical mechanism, and did not mean to infer that the behavior was otherwise in rural air. No actual rural air would be expected to be as pure as the "fictitious very pure air" of reaction *x*. Analyses of rust coatings acquired in rural air would be instructive. I would expect, as Mr. Comley does, that sulfates would be found present, although in smaller percentage than in industrial atmospheres.

Mr. Comley mentions, as evidence of an electrochemical mechanism, that iron corrodes at localized areas with the formation of pits. Pit depth measurements were made on all the specimens described in the paper. Measurements with flat micrometers showed the minimum decrease in thickness of the specimens to be less than 0.001 in., except in the case of very rapidly corroding steels which were perforated and beginning to disintegrate. In other words there was practically no corrosion at cathodic areas. On fast-corroding steels, the cathodic areas were small and the anodic areas large. On steels corroding slowly, the cathodic areas were large and the anodic areas small. Pit depths told the same general story as weight losses. Pit depths were deeper on the groundward surfaces than on the skyward.

Mr. Comley attempts considerable amplification of the rôle of basic sulfates. It would seem that his ideas would require the adherent rust to contain more sulfate than the outer loose rust. The few analyses in Table III and the data cited by Mr. Vernon seem to indicate the reverse to be true. Mr. Vernon is undoubtedly correct in emphasizing the condition of the corrosion products rather than the total quantities of copper or sulfate or other constituents. We agree with Mr. Comley that further analyses of adherent rust would be instructive.

Mr. Comley calls attention to the fact that the loose rust contained a very large excess of iron sulfate over nickel or copper sulfate. Perhaps this fact was not sufficiently emphasized in the paper but was the reason for speaking of complex basic sulfates of iron, copper, and nickel. Perhaps in conclusion 2, which is cited by Mr. Darrin, it would have been well to say "the function of copper and nickel is to render sulfates insoluble by forming complex basic sulfates of iron, copper, and nickel."

Mr. Comley prefers to treat his basic sulfates separately, but does it really make much difference? Basic sulfates are not usually considered as definite chemical compounds, but are more in the nature of solid solutions. In connection with Mr. Comley's statements it should be pointed out that the beneficial effects of nickel upon the weathering resistance of steel increase steadily with increasing nickel content and are enhanced by the addition of optimum amounts of copper.[20]

With regard to hygroscopicity, it would be expected that the moisture-retaining capacity of the rusts would be reflected in the moisture content determined during the analyses. In drying the rusts at 110 C., in general, more moisture was given off by rusts from slowly corroding steels than by rusts from fast corroding steels. This is contrary to the notion that hygroscopicity is important.

In this connection, a few specimens were blown off the Block Island racks by the hurricane of September, 1944. After lying in long grass for 10 months their weight losses were compared with those of identical specimens still in position on the racks. In all cases their weight losses were greater but not markedly so. These specimens were wet much longer, especially by dew, than those on the racks, and of course they were not washed as thoroughly by rain.

In reply to Mr. Vernon's specific question as regards the procedure followed in removing loose rust, this was the crude one of simply scraping the specimen with a blunt piece of steel and collecting the rust that fell off. Naturally it was impossible to scrape all specimens with the same thoroughness. It is felt that this accounts in part for the scatter shown in Fig. 6. Since the composition of the rust varied with depth, it is probable that the loose rust was not completely homogeneous. In general the loose rust came off in small nodules and these probably were not homogeneous throughout. Also the outer surface of the specimens was the part most subject to contamination. It is quite possible that some of the scatter may be real because the steels differed in composition in other elements than nickel and copper.

Mr. Darrin raises an interesting point in connection with fast corroding steel No. 44, in that the sulfate content of the skyward and groundward rust was practically identical. This steel was also exceptional in that its 25 day old rust contained more sulfate than the rust collected at 1, 2, and 3 years. On page 574 it was shown that soluble sulfate could be extracted from the rust on steel No. 44, but on page 559 no significant difference was found in the sulfate content of the rust after a 7-day dry spell and after a rainstorm. The behavior of steel No. 44 is probably tied in with its high purity, and the absence of addition elements likely to affect the corrosion products. The important point as regards the theory is that steel No. 44 had a very high corrosion rate and its rust a very low sulfate content. Steel No. 44 fits naturally into the curves of Fig. 4 and Fig. 6.

Mr. Leaf's experience that small changes in the compos tion of water in contact with steel may greatly affect corrosion rate supports the statement in conclusion 1 that the quality of the water contacting the steel surface is important in atmospheric corrosion. The fact that small changes in the silica content of the water influenced the corrosion may have some bearing on high silicon in some complex low alloy steels being beneficial in atmospheric corrosion.

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[20] N. B. Pilling and W. A. Wesley, "Atmospheric Durability of Steels Containing Nickel and Copper," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 643 (1940).

Mr. Holler's idea of defining a unit of corrosivity is interesting, but owing to the complexity and variety of weather many pitfalls would be expected. One seemingly insurmountable difficulty is that variations in the weather affect different steels differently. This was brought out in the paper in discussing Fig. 10. It is certain that relative merit ratings of steels would be different with exposures started at different times, and it is conceivable that there might be some minor changes in position. What then happens to the unit of corrosivity?

Mr. Smith's reference to edge corrosion in the Annapolis tests is much appreciated. The rest of the discussion does not seem to require comment, but the author considers all the discussion quite pertinent and helpful.

THE EFFECT OF THE IRON CONTENT OF CUPRO-NICKEL ON ITS CORROSION RESISTANCE IN "SEA WATER"

BY A. W. TRACY[1] AND R. L. HUNGERFORD[1]

SYNOPSIS

Data are given on a laboratory investigation concerning the effect of iron additions to cupro-nickels on the corrosion resistance of the alloys exposed to "sea water" in motion. The "sea water" was a 3 per cent solution of sea salt. Sheet metal specimens were tested by attaching to fiber disks which were rotated in the test solution and tube specimens were placed in an experimental condenser.

The extent of corrosion was determined on sheet metal specimens by measuring losses in thickness by means of sharp-pointed micrometers. Corrosion of tube specimens was judged from visual examinations.

The tests showed quite conclusively the effect of iron content in improving the corrosion resistance of cupro-nickels in sea water and indicated that as the nickel content of the alloy was decreased, increasing amounts of iron were required for optimum corrosion resistance.

Copper-nickel alloys are used extensively in the form of tubes, pipes, and plates on shipboard for the construction of surface condensers and salt water lines, and are finding increased use in oil refineries for heat-exchanger tubes. Thirty per cent cupro-nickel is used for condenser tubes and salt water lines on ships of the U. S. Navy, and has been considered more corrosion resistant to rapidly flowing sea water than the copper-nickel alloys lower in nickel.[2]

Some work done in England[3] indicated that increasing the iron and manganese content of a 30 per cent cupro-nickel likewise increased the resistance to corrosion by sea water. It was stated that as the manganese was increased, smaller amounts of iron were required so that the sum of the iron plus one fifth the manganese content should not be less than 0.5 per cent; further, that the manganese should not be less than 0.25 per cent nor more than 2 per cent, and that the iron should be not less than 0.3 per cent nor more than 1 per cent.

LaQue[4] has reported some tests on 30 per cent cupro-nickel in sea water at very low velocity, and confirmed the conclusion that substantial additions of iron increase corrosion resistance.

APPARATUS AND METHOD

An investigation of the effect of iron content on the corrosion resistance of cupro-nickels in "sea water" was started in the laboratories of The American Brass Co. in October, 1939, with particular interest in conditions of severe impingement corrosion. Tests were made in a vertical-shaft impingement tester, shown in Figs. 1 and 2, and in a horizontal-shaft impingement tester, shown in Fig. 3.

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[1] Assistant Metallurgist and Laboratory Assistant, respectively, Technical Dept., The American Brass Co., Waterbury, Conn.

[2] H. G. Steel, "Copper and Its Alloys in Wrought Form," *Metal Progress*, Am. Soc. Metals, October, 1943, p. 720.

[3] Cupro-Nickel Condenser Tubes—Effect of Minor Constituents (Iron and Manganese), British Non-Ferrous Metals Res. Assn., Publication D-31, January, 1939.

[4] F. L. LaQue, "The Behavior of Nickel-Copper Alloys in Sea Water," *Journal*, Am. Soc. Naval Eng., Vol. 1, No. 53, p. 29 (1941).

Figure 1 is a general view of the vertical-shaft impingement tester. The Everdur tank is 50 in. long by 20 in. wide by 24 in. deep, and holds 70 gal.

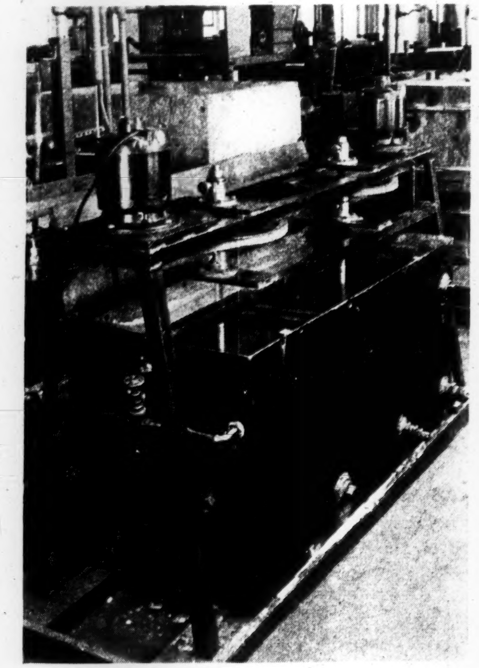

FIG. 1.—General View of Vertical Shaft Impingement Tester.

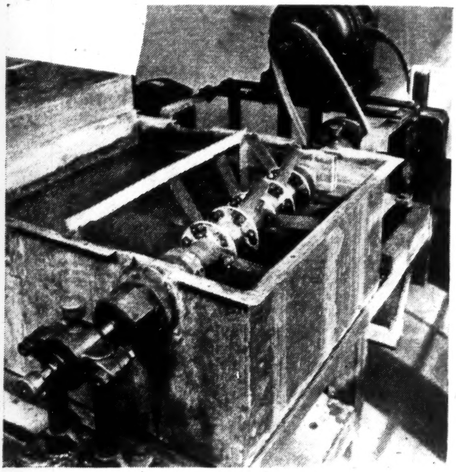

FIG. 3. Construction of Horizontal-Shaft Impingement Tester.

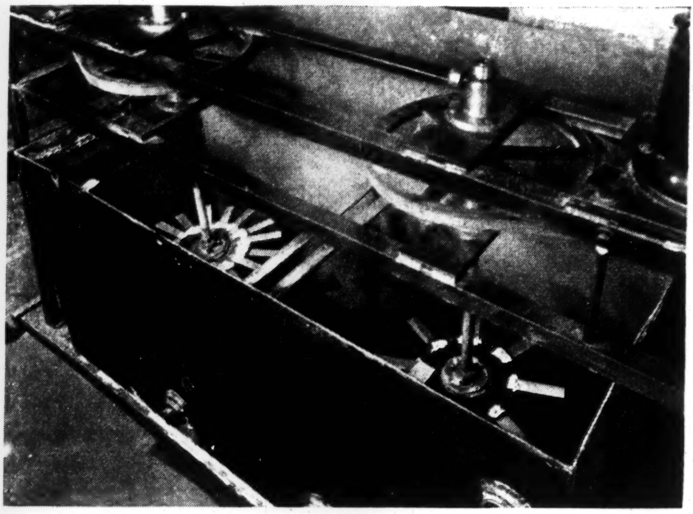

FIG. 2.—Method of Attaching Sheet Metal Strips to Fiber Disks on Lower Ends of Shafts.

of test solution. The shafts rotate at 322 rpm.

Figure 2 illustrates the method of attaching sheet-metal strips to fiber disks on the lower ends of the shafts. The velocity of the outer end of a test specimen is naturally controlled by the length of the specimen, the diameter of the disk, and the speed of the shaft.

Each specimen was fastened to the disk by two Everdur bolts. The bolts and nuts and the portion of the specimen on the disk were protected from corrosion by paint or lacquer, which also prevented any galvanic effect. A 3 per cent solution of Turk's Island sea salt was used for the test solution. This sea salt was readily available on the market until war-time conditions cut off the supply. It has been analyzed as follows:

Sodium chloride, per cent	98.55
Potassium chloride, per cent	0.04
Magnesium chloride, per cent	0.17
Magnesium sulfate, per cent	0.05
Calcium sulfate, per cent	0.13
Ammonium chloride, per cent	0.001
Not determined, per cent	1.06

The construction of the horizontal-shaft impingement tester is shown in Fig. 3. This equipment is a mechanically improved form of the test equipment described in a discussion of a paper by Borgmann and Mears.[5] Sheet metal specimens were attached to phenol-formaldehyde fiber disks on a shaft rotating at 1060 rpm. partially immersed in 3 per cent sea salt solution. The Everdur bolts and nuts used in attaching the specimens were covered with paint or lacquer to protect them from corrosion and prevent any possible galvanic action. As the specimens were rotated by the shaft, they were whirled into and out of the water, churning large volumes of air in the form of bubbles into the water. Obviously, the tank must be covered to prevent the solution from being thrown out.

The test specimens were strips 1 in. wide by 0.040 to 0.050 in. gage, and of a length varying from 2 to 6 in. to give the desired velocity at the outer end of the specimens. Most of the alloys tested were cast and rolled in the laboratory, but a few were from regular mill production. In all cases, the metal strips were finished by cold rolling. All sheet-metal specimens, after shearing to size and drilling support holes, were annealed at 700 C. for 1 hr. and water quenched.

Annealing scales were removed by pickling in a cold solution containing approximately 5 per cent sodium bichromate and 15 per cent sulfuric acid by weight. In some cases, stubborn scales were removed in a cold solution containing 50 per cent sulfuric acid and 50 per cent nitric acid by volume. All specimens were finally pickled in cold 10 per cent sulfuric acid solution (by weight) in order to eliminate the possibility of initial passive films on the specimens. Alloys in the form of tubes, for test in an experimental condenser, to be described later, were obtained from the mill.

The degree of corrosion was determined by measuring the thickness of specimens before and after test, using sharp-pointed micrometers. The figures given in this report are one half the actual loss in thickness and may be considered comparable to the loss in wall thickness of a tube being corroded from one side only. Points *A*, *B*, *C*, and *D* were arbitrarily selected for measuring losses in thickness. Measurement *A* was taken $\frac{1}{16}$ in. from the leading edge and $\frac{1}{16}$ in. from the outer end. Measurement *B* was taken similarly on the trailing edge. Measurement *C* was taken $\frac{1}{16}$ in. from the leading edge and

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[5] Symposium on Corrosion Testing Procedures, Chicago Regional Meeting, Am. Soc. Testing Mats., p. 32 (1937). (Symposium issued as separate publication.)

TABLE I.—COMPOSITION OF METALS BY ANALYSIS.

Analysis Reference Number	Alloy	Copper, per cent	Nickel, per cent	Iron, per cent	Manganese, per cent	Zinc, per cent	Total Carbon, per cent	Other Elements, per cent
1	Copper	99.960	...	...	...	...	...	Phosphorus 0.033
2	Admiralty—plain	70.58	...	0.01	...	28.33	...	Arsenic 0.004, lead 0.02, tin 1.06
3	Admiralty—arsenical	70.71	...	0.02	...	28.08	...	Arsenic 0.03, lead 0.01, tin 1.15
4	Aluminum brass	76.42	...	0.07	...	21.46	...	Arsenic 0.056, aluminum 1.98, lead 0.01
5	30% cupro-nickel	69.02	30.39*	0.05	0.29	0.20	0.042	Lead 0.01
6	30% cupro-nickel, 0.50% iron	68.09	29.92	0.45	1.20	0.30	0.040	Lead 0.00
7	Special 10% nickel silver	56.61	10.50	0.09	0.06	32.73*	...	Lead 0.012, tin 0.00
8	30% cupro-nickel	69.06	29.10*	0.057	0.76	...	0.023	
9	30% cupro-nickel, 0.10% iron	69.06	30.06*	0.10	0.76	...	0.019	
10	30% cupro-nickel, 0.20% iron	68.94	30.08*	0.20	0.77	...	0.015	
11	30% cupro-nickel, 0.30% iron	68.96	30.01*	0.28	0.74	...	0.006	
12	30% cupro-nickel, 0.40% iron	69.39	29.40*	0.43	0.77	...	0.011	
13	30% cupro-nickel, 0.50% iron	68.80	29.91*	0.50	0.78	...	0.011	
14	30% cupro-nickel, 0.75% iron	68.33	30.14*	0.76	0.76	...	0.012	
15	30% cupro-nickel, 1.00% iron	68.13	30.12*	0.99	0.76	...	0.004	
16	30% cupro-nickel, 1.25% iron	67.53	30.44*	1.26	0.76	...	0.006	
17	30% cupro-nickel, 1.50% iron	67.46	30.25*	1.52	0.76	...	0.006	
18	30% cupro-nickel, 0.50% iron	69.54	29.94*	0.51	0.00	...	0.012	
19	10% cupro-nickel	89.73	10.11	0.003	0.19	...	...	
20	10% cupro-nickel, 0.10% iron	89.55	10.15	0.11	0.19	...	...	
21	10% cupro-nickel, 0.25% iron	89.52	10.03	0.26	0.19	...	...	
22	10% cupro-nickel, 0.50% iron	89.16	10.13	0.51	0.18	...	...	
23	10% cupro-nickel, 0.75% iron	88.92	10.14	0.77	0.18	...	...	
24	10% cupro-nickel, 1.00% iron	88.75	10.17	1.04	0.20	...	...	
25	10% cupro-nickel, 1.50% iron	88.26	10.18	1.52	0.19	...	...	
26	20% cupro-nickel	79.69	20.16	0.004	0.28	...	...	
27	20% cupro-nickel, 0.10% iron	79.56	20.21	0.11	0.28	...	...	
28	20% cupro-nickel, 0.25% iron	79.40	20.28	0.26	0.28	...	...	
29	20% cupro-nickel, 0.50% iron	79.00	20.26	0.50	0.28	...	...	
30	20% cupro-nickel, 0.75% iron	78.80	20.22	0.76	0.28	...	...	
31	20% cupro-nickel, 1.00% iron	78.46	20.23	1.00	0.28	...	...	
32	20% cupro-nickel, 1.50% iron	78.02	20.26	1.50	0.28	...	...	
33	10% cupro-nickel, 0.3% iron	89.54	9.90*	0.29	0.27	0.00	...	
34	10% cupro-nickel, 0.75% iron	89.21	9.69*	0.80	0.12	0.17	0.003	Lead 0.004
35	30% cupro-nickel	69.81	29.91*	0.01	0.27	0.00	...	
36	30% cupro-nickel	68.97	30.36*	0.04	0.62	...	0.008	
37	30% cupro-nickel, 0.5% iron	68.73	30.02*	0.48	0.77	...	0.004	
38	30% cupro-nickel, 0.50% iron	69.21	30.01*	0.51	0.27	0.00	...	
39	2% cupro-nickel	97.93	1.98	0.005	0.08	...	...	
40	2% cupro-nickel, 0.10% iron	97.85	2.01	0.097	0.086	...	...	
41	2% cupro-nickel, 0.25% iron	97.72	1.99	0.25	0.08	...	...	
42	2% cupro-nickel, 0.50% iron	97.44	2.01	0.50	0.075	...	...	
43	2% cupro-nickel, 0.75% iron	97.22	1.99	0.75	0.09	...	...	
44	2% cupro-nickel, 1.00% iron	96.94	2.03	1.01	0.084	...	...	
45	2% cupro-nickel, 1.50% iron	96.45	2.01	1.52	0.09	...	...	
46	5% cupro-nickel	95.17	4.78	0.005	0.077	...	...	
47	5% cupro-nickel, 0.10% iron	94.79	5.01	0.098	0.09	...	...	
48	5% cupro-nickel, 0.25% iron	94.80	4.92	0.26	0.09	...	...	
49	5% cupro-nickel, 0.50% iron	94.54	4.92	0.49	0.09	...	...	
50	5% cupro-nickel, 0.75% iron	94.14	4.98	0.76	0.094	...	...	
51	5% cupro-nickel, 1.00% iron	93.94	5.03	1.00	0.095	...	...	
52	5% cupro-nickel, 1.50% iron	93.43	5.04	1.49	0.07	...	...	
53	Copper	99.89	...	0.003	0.088	...	...	
54	Copper, 0.87% iron	99.05	...	0.87	0.09	...	...	

TABLE I.—*Continued*

Analysis Reference Number	Alloy	Copper, per cent	Nickel, per cent	Iron, per cent	Manganese, per cent	Zinc, Per cent	Total Carbon, per cent	Other Elements, per cent
55......	30% cupro-nickel	69.99	29.72*	0.07	0.22	0.00	...	
56......	30% cupro-nickel, 0.50% iron	68.05	29.95*	0.45	1.25	0.30	...	Lead 0.00
57......	10% cupro-nickel	89.45	10.27	0.05	0.23	0	...	
58......	Admiralty—arsenical	70.99	...	0.01	...	27.93	...	Lead 0.02, tin 1.02, arsenic 0.032
59......	Aluminum brass	76.94	...	0.03	...	21.04	...	Lead 0.005, aluminum 1.94, arsenic 0.04

* By difference.

¼ in. from the edge of the supporting disk. Measurement *D* was taken similarly on the trailing edge.

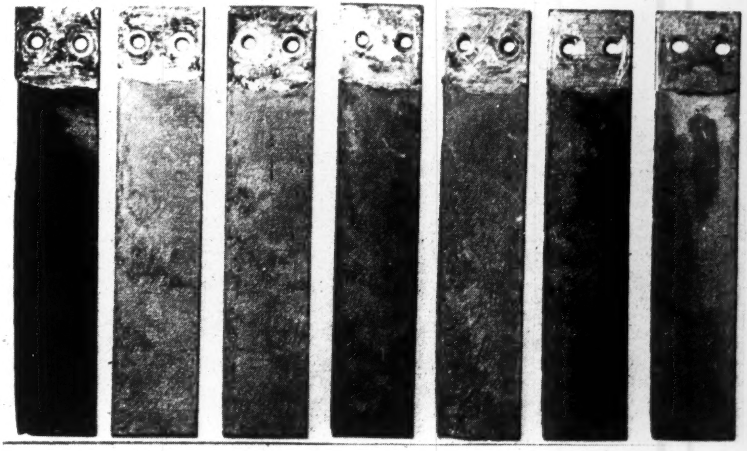
The maximum loss in thickness (also measured) was usually the same as measurement *A*, but in a few instances was nearer the center of rotation.

Test-run Nos. 12, 24, 25, 27, 28, 29, and 32 gave data pertinent to the effect of iron on the corrosion resistance of copper-nickel alloys.

TESTS ON VERTICAL-SHAFT IMPINGEMENT TESTER

Run No. 12—Preliminary:

Duplicate specimens of copper, plain admiralty, arsenical admiralty, aluminum brass, 30 per cent cupro-nickel with low iron, 30 per cent cupro-nickel with 0.45 per cent iron, and a special 10 per cent nickel silver were tested on the vertical-shaft impingement tester for 26 weeks at a peripheral velocity of 8 ft.



	Copper	Admiralty	Arsenical Admiralty	Aluminun Brass	30% Cupro-Nickel 0.05% Fe 0.29% Mn	30% Cupro-Nickel 0.45% Fe 1.20% Mn	Special 10% Nickel Silver
Analysis Reference No.	1	2	3	4	5	6	7
Max. Depth of Corrosion, in....................	0.022	0.000	0.000	0.007	0.025	0.000	0.010

FIG. 4.—Test on Vertical Shaft Impingement Tester—Run No. 12.

3 per cent sea salt solution, room temperature. Peripheral velocity 8 ft. per sec. Duration of test = 26 weeks. Leading edge of specimen on left.

per sec. This particular test was made in a crude predecessor of the apparatus shown in Figs. 1 and 2.

TABLE II.—TEST ON VERTICAL-SHAFT IMPINGEMENT TESTER—RUN NO. 12 AT 8 FT. PER SEC. FOR 26 WEEKS, ROOM TEMPERATURE.

	Analysis Reference Number	Penetration, in.					Remarks
		At Point *A*	At Point *B*	At Point *C*	At Point *D*	Maximum	
Copper	1	0.017 0.022	0.012 0.012	0.011 0.010	0.011 0.007	0.017 0.022	No visible film
Admiralty, plain	2	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	Green film
Arsenical	3	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	Green film
Aluminum brass	4	0.000 0.007	0.000 0.000	0.002 0.000	0.000 0.000	0.010 0.007	Thin green film except in pitted areas
30% cupro-nickel	5	0.025 0.025	0.000 0.000	0.000 0.000	0.000 0.000	0.025 0.025	Thin green film
30% cupro-nickel, 0.50% iron	6	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.001 0.000	Dark green film
Special 10% nickel silver	7	0.008 0.010	0.000 0.006	0.001 0.001	0.000 0.000	0.008 0.010	Gray-green film

At points *A* and *B* (1/16 in. from outer edge) velocity = 8 ft. per sec.
At points *C* and *D* (1/16 in. from supporting disk) velocity = 4 ft. per sec.
Points *A* and *C* on leading edge.
Points *B* and *D* on trailing edge.

TABLE III.—30 PER CENT CUPRO-NICKEL TEST ON VERTICAL-SHAFT IMPINGEMENT TESTER—RUN NO. 25 AT 20 FT. PER SEC. FOR 12 WEEKS, ROOM TEMPERATURE.

Analysis	Analysis Reference Number	Penetration, in.					Remarks
		At Point *A*	At Point *B*	At Point *C*	At Point *D*	Maximum	
30% cupro-nickel, 0.06% iron	8	0.014	0.006	0.006	0.001	0.016	Gray-green film near low velocity end of specimen
30% cupro-nickel, 0.10% iron	9	0.008	0.002	0.001	0.000	0.011	Gray film
30% cupro-nickel, 0.20% iron	10	0.005	0.001	0.002	0.000	0.006	Gray film with some green
30% cupro-nickel, 0.30% iron	11	0.004	0.001	0.000	0.000	0.004	
30% cupro-nickel, 0.40% iron	12	0.002	0.000	0.001	0.000	0.003	
30% cupro-nickel, 0.50% iron	13	0.002	0.001	0.000	0.000	0.003	
30% cupro-nickel, 0.75% iron	14	0.002	0.001	0.000	0.000	0.003	
30% cupro-nickel, 1.00% iron	15	0.001	0.001	0.000	0.000	0.001	Thin greenish film
30% cupro-nickel, 1.25% iron	16	0.001	0.000	0.001	0.000	0.001	
30% cupro-nickel, 1.50% iron	17	0.001	0.000	0.000	0.000	0.001	
30% cupro-nickel, 0.50% iron, 0% manganese	18	0.001	0.001	0.000	0.000	0.002	
30% cupro-nickel, 0.50% iron, 1.20% manganese	6	0.001	0.000	0.000	0.000	0.002	Light green film with dark green at leading edge
30% cupro-nickel, 0.05% iron, mill stock	5	0.010	0.000	0.001	0.000	0.013	Dark green except near low velocity end of specimen

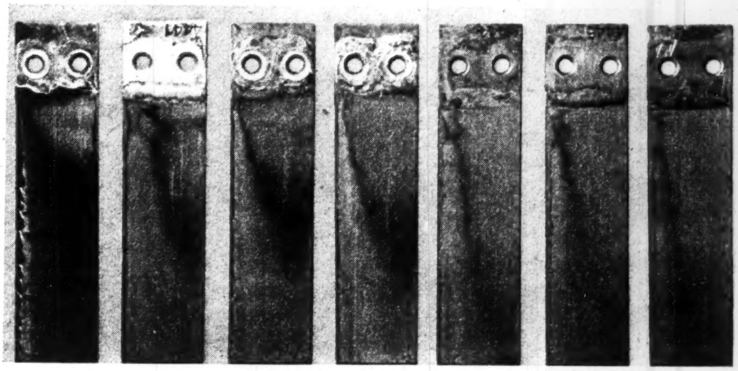
At points *A* and *B* (1/16 in. from outer edge) velocity = 20 ft. per sec.
At points *C* and *D* (1/16 in. from supporting disk) velocity = 12 ft. per sec.
Points *A* and *C* on leading edge.
Points *B* and *D* on trailing edge.

The condition of the tested specimens is illustrated in Fig. 4. The numbers on the line designated "analysis reference number" refer to the numbered analyses in Table I. The losses in thickness are given in Table II and the maximum losses are shown in Fig. 13.

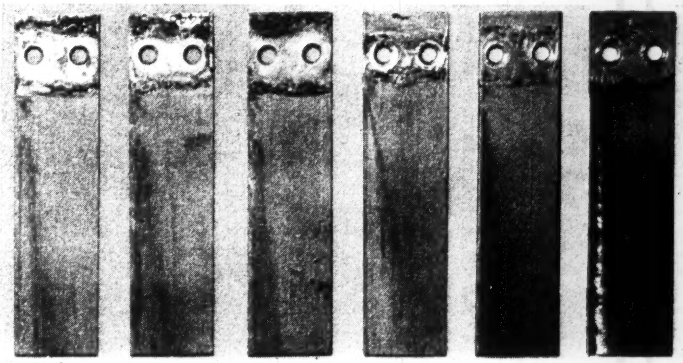
The photograph and the data indicate the relatively poor resistance of copper to impingement corrosion and the good resistance of admiralty and aluminum brass in this test. The improvement in resistance to impingement corrosion of the 30 per cent cupro-nickel with 0.45 per cent iron is outstanding. The special 10 per cent nickel silver showed fair resistance to impingement corrosion.

Run No. 25—30 per cent Cupro-Nickel Series:

Single specimens of 30 per cent cupro-nickel containing up to 1.5 per cent iron and a short series with 0.50 per cent iron and varying manganese content were included in this test. The test was made at a peripheral velocity of 20 ft. per sec. and ran for 12 weeks. Figure 5 shows the condition of the specimens at the end of the test. Data giving measurements of losses in thickness are given in Table III, and the maximum losses in thickness are plotted in Fig. 14. The beneficial effect of the increasing iron additions was definite. Good resistance to impingement was established at about 0.30 per cent iron; iron up to 1 per cent produced increased resistance, with little change up to 1.5 per cent iron. The specimens with 0.5 per cent iron and 0, 0.75, and 1.20 per cent manganese



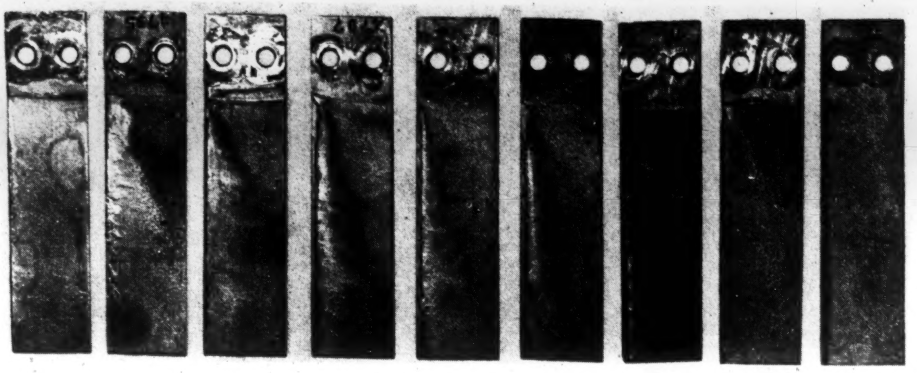
Iron, per cent	0.06	0.10	0.20	0.28	0.43	0.50	0.76
Manganese, per cent	0.76	0.76	0.77	0.74	0.74	0.78	0.76
Analysis Reference No.	8	9	10	11	12	13	14
Max. Depth of Corrosion, in.	0.016	0.011	0.006	0.004	0.003	0.003	0.003



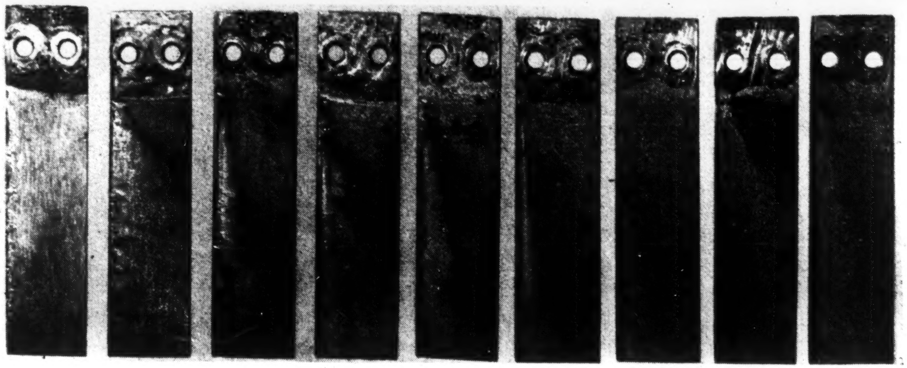
Iron, per cent	0.99	1.26	1.52	0.51	0.45	0.05
Manganese, per cent	0.76	0.76	0.76	0.00	1.20	0.29
					Zinc 0.30	0.20
Analysis Reference No.	15	16	17	18	6	5
Max. Depth of Corrosion, in.	0.001	0.001	0.001	0.002	0.002	0.013

FIG. 5.—30 per cent Cupro-Nickel Series on Vertical Shaft Impingement Tester—Run No. 25.

3 per cent sea salt solution, room temperature. Peripheral velocity 20 ft. per sec. Duration of test = 12 weeks. Leading edge on left.



								30% Cupro-Nickel	
Iron, per cent	0.003	0.11	0.26	0.51	0.77	1.04	1.52	0.04	0.48
Manganese, per cent	0.19	0.19	0.19	0.18	0.18	0.20	0.19	0.62	0.77
Nom. Nickel, per cent	10	10	10	10	10	10	10	30	30
Analysis Reference No.	19	20	21	22	23	24	25	13	14
Max. Depth of Corrosion, in.	0.008	0.009	0.008	0.006	0.004	0.000	0.004	0.012	0.006



								30% Cupro-Nickel	
Iron, per cent	0.004	0.11	0.26	0.50	0.76	1.00	1.50	0.04	0.48
Manganese, per cent	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.62	0.77
Nom. Nickel, per cent	20	20	20	20	20	20	20	30	30
Analysis Reference No.	26	27	28	29	30	31	32	13	14
Max. Depth of Corrosion, in.	0.010	0.010	0.007	0.005	0.004	0.006	0.002	0.012	0.006

FIG. 6. 10 and 20 per cent Cupro Nickel Series on Vertical Shaft Impingement Tester. Run No. 24.

TABLE IV.—10 AND 20 PER CENT CUPRO-NICKELS TEST ON VERTICAL-SHAFT IMPINGEMENT TESTER —RUN NO. 24 AT 20 FT. PER SEC. FOR 10 WEEKS, ROOM TEMPERATURE.

	Analysis Reference Number	Penetration, in.					Remarks
		At Point *A*	At Point *B*	At Point *C*	At Point *D*	Maximum	
10% cupro-nickel, 0% iron	19	0.009 0.008	0.005 0.004	0.006 0.005	0.004 0.003	0.009 0.008	No visible film
10% cupro-nickel, 0.1% iron	20	0.007 0.009	0.005 0.004	0.005 0.008	0.001 0.001	0.007 0.008	Patch of green film near low velocity end of specimen
10% cupro-nickel, 0.25% iron	21	0.006 0.008	0.002 0.002	0.003 0.002	0.001 0.001	0.006 0.008	Triangle of green film reaching out from low velocity end of specimen
10% cupro-nickel, 0.50% iron	22	0.005 0.006	0.000 0.000	0.001 0.001	0.000 0.000	0.005 0.006	
10% cupro-nickel, 0.75% iron	23	0.004 0.004	0.000 0.000	0.001 0.000	0.000 0.000	0.004 0.004	Slightly greater portion filmed over
10% cupro-nickel, 1.00% iron	24	0.004 0.000	0.000 0.000	0.001 0.000	0.000 0.000	0.004 0.000	Green film except just in back of leading edge
10% cupro-nickel, 1.50% iron	25	0.003 0.004	0.000 0.000	0.001 0.000	0.000 0.000	0.003 0.004	Dark green film except corroded streak in back of leading edge
20% cupro-nickel, 0% iron	26	0.010 0.010	0.006 0.006	0.008 0.008	0.005 0.005	0.010 0.010	No visible film
20% cupro-nickel, 0.10% iron	27	0.009 0.010	0.004 0.004	0.005 0.005	0.001 0.000	0.009 0.010	Small patch of green near low velocity end of specimens
20% cupro-nickel, 0.25% iron	28	0.007 0.007	0.001 0.001	0.001 0.001	0.000 0.000	0.007 0.007	Large triangle of green film reaching out from low velocity end of specimen
20% cupro-nickel, 0.50% iron	29	0.005 0.005	0.001 0.002	0.001 0.000	0.000 0.000	0.005 0.005	
20% cupro-nickel, 0.75% iron	30	0.002 0.004	0.001 0.000	0.001 0.000	0.000 0.000	0.002 0.004	
20% cupro-nickel, 1.00% iron	31	0.002 0.006	0.000 0.001	0.001 0.000	0.000 0.000	0.002 0.006	Green film except just in back of leading edge
20% cupro-nickel, 1.50% iron	32	0.002 0.002	0.000 0.000	0.000 0.000	0.000 0.000	0.002 0.002	Almost entirely covered with green film
30% cupro-nickel, 0.04% iron	13	0.012 0.012	0.006 0.006	0.007 0.008	0.000 0.001	0.012 0.012	Small area of green film near low velocity end of specimens
30% cupro-nickel, 0.50% iron	14	0.004 0.006	0.000 0.000	0.000 0.001	0.000 0.000	0.004 0.006	Triangle of green over one half of specimens

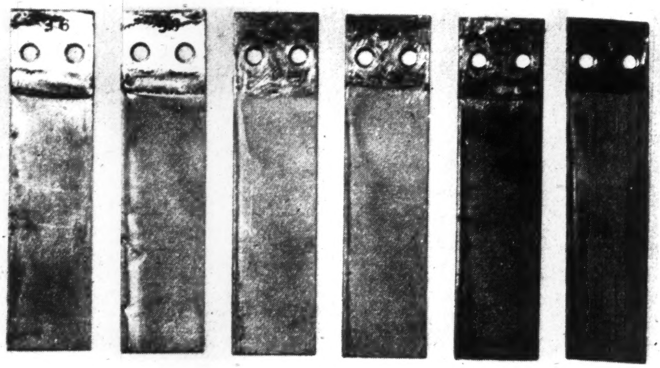
At Points *A* and *B* (1/16 in. from outer edge) velocity = 20 ft. per sec.
At Points *C* and *D* (1/16 in. from supporting disk) velocity = 12 ft. per sec.
Points *A* and *C* on leading edge.
Points *B* and *D* on trailing edge.

indicated that, within limits, manganese appears to be without significant effect on the impingement corrosion of these alloys.

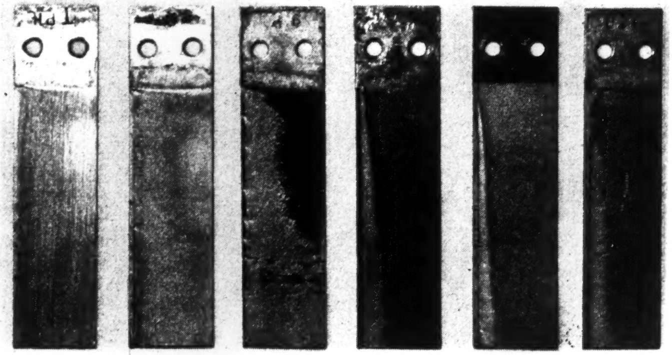
The presence of 0.20 per cent zinc in 30 per cent cupro-nickel free from iron had no significant effect on the corrosion rate as can be seen in Fig. 5 by comparing No. 8, which was free from zinc, and No. 5 which contained 0.20 per cent zinc. Likewise, comparing No. 6 and No. 12 it can be seen that 0.30 per cent zinc had no significant effect on the impingement resistance of 70-30 cupro-nickel with 0.5 per cent iron.

Run No. 24—10 and 20 per cent Cupro-Nickel Series:

A series of duplicate specimens of 10 and 20 per cent cupro-nickels with iron contents ranging up to 1.5 per cent was compared with two 30 per cent cupro-nickel specimens; one substantially free from iron, and the other with 0.5 per cent iron. The manganese content was maintained at about 0.2 per cent for the 10 per cent cupro-nickels, and 0.3 per cent for the 20 per cent cupro-nickels to obtain sound bars in casting. All the bars, from which these specimens were prepared, were cast and rolled in the laboratory. The losses in thickness in this test were lower than those in the test previously described, as the duration of the test was shorter.



Iron, per cent	0.003	0.51	0.77	1.04	0.29	0.80
Manganese, per cent	0.19	0.18	0.18	0.20	0.27	0.12
Nom. Nickel, per cent	10	10	10	10	10	10
Analysis Reference No.	19	22	23	24	33	34
Max. Depth of Corrosion, in.	0.008	0.006	0.008	0.004	0.010	0.004



Iron, per cent	0.80	0.80	0.01	0.04	0.48	0.51
Manganese, per cent	0.12	0.12	0.27	0.62	0.77	0.27
Nom. Nickel, per cent	10	10	30	30	30	30
Analysis Reference No.	34	34	35	36	37	38
Max. Depth of Corrosion, in.	0.005	0.004	0.012	0.010	0.004	0.003

FIG. 7.—10 and 30 per cent Cupro-Nickel Series on Vertical Shaft Impingement Tester—Run No. 27.

3 per cent sea salt solution, room temperature. Peripheral velocity 26 ft. per sec. Duration of test = 8 weeks. Leading edge on left.

The results of the test are given in Table IV and Fig. 15. Figure 6 shows the condition of the 10 per cent cupro-nickel specimens compared to 30 per cent cupro-nickels with and without iron.

It is evident that about 0.5 per cent iron was required to reduce definitely the impingement corrosion of 10 per cent cupro-nickel and that 0.75 to 1 per cent iron was quite effective. At 1.5 per cent, the good effect of iron was maintained. The data indicate that 30 per cent cupro-nickel without iron was corroded to a greater extent than 10 per cent cupro-nickel without iron. This apparent anomaly was not confirmed by tests in an experimental condenser nor with results obtained with the horizontal-shaft impingement tester, which will be discussed later.

The 20 per cent cupro-nickel series showed improved impingement resistance as the iron content was increased. The results are shown in Table IV and Fig. 15 and the condition of specimens shown in Fig. 6.

TABLE V.—10 AND 30 PER CENT CUPRO-NICKELS TEST ON VERTICAL-SHAFT IMPINGEMENT TESTER—RUN NO. 27 AT 26 FT. PER SEC. FOR 8 WEEKS, ROOM TEMPERATURE.

	Analysis Reference Number	Penetration, in.					Remarks
		At Point *A*	At Point *B*	At Point *C*	At Point *D*	Maximum	
10% cupro-nickel, 0% iron	19	0.008 0.008	0.004 0.005	0.008 0.008	0.006 0.006	0.008 0.008	No visible film
10% cupro-nickel, 0.50% iron	22	0.006 0.006	0.001 0.001	0.001 0.002	0.000 0.000	0.006 0.006	
10% cupro-nickel, 0.75% iron	23	0.004 0.005	0.000 0.001	0.002 0.001	0.000 0.000	0.006 0.008	Small area of faint green film near low velocity end of specimens
10% cupro-nickel, 1.00% iron	24	0.002 0.004	0.000 0.000	0.001 0.000	0.000 0.000	0.003 0.004	No perceptible film
10% cupro-nickel, 0.30% iron, mill stock	33	0.009	0.003	0.002	0.001	0.010	Traces of green film near low velocity end of specimens
10% cupro-nickel, 0.80% iron, tube pierced	34	0.004 0.004	0.000 0.001	0.001 0.000	0.000 0.000	0.008 0.004	No visible film
10% cupro-nickel, 0.80% iron, tube extruded	34	0.004 0.004	0.000 0.001	0.001 0.001	0.000 0.000	0.004 0.005	
10% cupro-nickel, 0.80% iron, tube pierced, unannealed	34	0.004	0.000	0.001	0.000	0.004	
30% cupro-nickel, 0.01% iron, 0.27% manganese	35	0.010	0.007	0.008	0.000	0.012	Triangle of dark green near low velocity end covering one third of area
30% cupro-nickel, 0.04% iron, 0.62% manganese	36	0.008	0.000	0.003	0.000	0.010	Dark green except just behind leading edge
30% cupro-nickel, 0.50% iron, 0.77% manganese	37	0.001 0.002	0.000 0.000	0.000 0.001	0.000 0.000	0.002 0.004	Light green except just behind leading edge
30% cupro-nickel, 0.50% iron, 0.27% manganese	38	0.003	0.001	0.001	0.000	0.003	

At points *A* and *B* (1/16 in. from outer edge) velocity = 26 ft. per sec.
At points *C* and *D* (1/16 in. from supporting disk) velocity = 18 ft. per sec.
Points *A* and *C* on leading edge.
Points *B* and *D* on trailing edge.

Run No. 27—10 and 30 per cent Cupro-Nickel Series:

Run No. 27 was made at a peripheral velocity of 26 ft. per sec. for 8 weeks on specimens of 10 and 30 per cent cupro-nickels in duplicate. The composition and final condition of the specimens are given in Fig. 7. Data on loss-in-thickness measurements are given in Table V. The maximum depths of corrosion are given in Fig. 16. In this test, the effect of iron on the corrosion resistance of

10 per cent cupro-nickel was not very consistent, but special attention is drawn to the specimens designated as No. 34, Fig. 7. These strips were made by splitting $\frac{5}{8}$-in. outside diameter by 0.049-in. gage tubes longitudinally and flattening. The first specimen No. 34 was taken from a tube made by piercing on the Mannesmann machine, rolling, and drawing. The second specimen No. 34 was taken from a tube made by extruding, rolling, and drawing. As previously mentioned, the tests were ordinarily made on specimens annealed for 1 hr. at 700 C. prior to testing. The third specimen No. 34 was made by splitting a hard-drawn tube longitudinally and flattening to form a sheet specimen without annealing. There was no significant difference in corrosion resistance between hard and annealed specimens, nor was there any significant difference in corrosion due to the two methods of fabrication. In Fig. 7, specimen No. 33 (10 per cent cupro-nickel, 0.29 per cent iron, and 0.27 per cent manganese) was taken from a lot of sheet metal made in the mill. Apparently 0.29 per cent iron in 10 per cent cupro-nickel was not sufficient to give outstanding resistance to impingement corrosion.

TABLE VI.—10 AND 30 PER CENT CUPRO-NICKELS TEST ON HORIZONTAL-SHAFT IMPINGEMENT TESTER—RUN NO. 28 AT 48 FT. PER SEC. FOR 8 WEEKS AT 100 F.

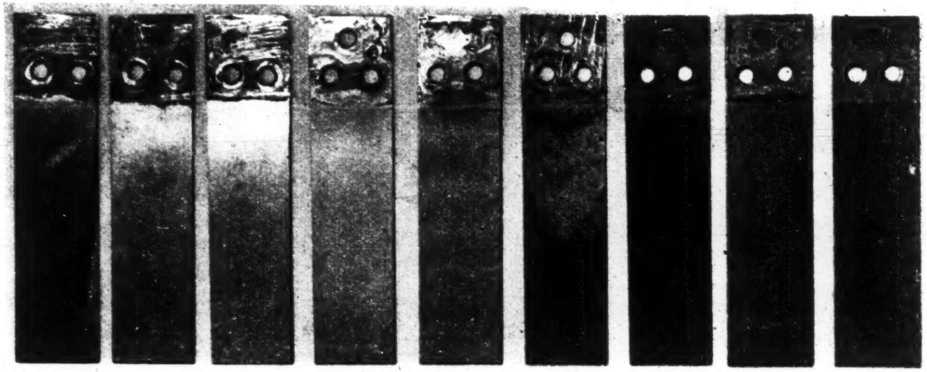
	Analysis Reference Number	Penetration, in.					Remarks
		At Point *A*	At Point *B*	At Point *C*	At Point *D*	Maximum	
10% cupro-nickel, 0% iron	19	0.005 0.004	0.000 0.000	0.000 0.000	0.000 0.000	0.010 0.010	Slight brownish film
10% cupro-nickel, 0.50% iron	22	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.003 0.004	
10% cupro-nickel, 0.75% iron	23	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	
10% cupro-nickel, 1.00% iron	24	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	
10% cupro-nickel, 0.80% iron, tube pierced	34	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.001 0.000	
10% cupro-nickel, 0.80% iron, tube extruded	34	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.000	0.000 0.005	
30% cupro-nickel, 0.01% iron, 0.27% manganese	35	0.000	0.000	0.000	0.000	0.000	Thin, light green film
30% cupro-nickel, 0.04% iron, 0.62% manganese	36	0.000	0.000	0.000	0.000	0.001	Thin, dark green film
30% cupro-nickel, 0.50% iron, 0.77% manganese	37	0.000	0.000	0.000	0.000	0.000	Thin, greenish film
30% cupro-nickel, 0.50% iron, 0.27% manganese	38	0.000	0.000	0.000	0.000	0.000	

At points *A* and *B* (1/16 in. from outer edge) velocity = 48 ft. per sec.
At points *C* and *D* (1/16 in. from supporting disk) velocity = 22 ft. per sec.
Points *A* and *C* on leading edge.
Points *B* and *D* on trailing edge.

The good effect of the iron content of 30 per cent cupro-nickel on its resistance to impingement corrosion is again apparent from the study of Fig. 7, Table V, or Fig. 16. The data also indicate that the manganese content is not critical in relation to the corrosion resistance of the alloy.

Run No. 29—2 and 5 per cent Cupro-Nickel Series:

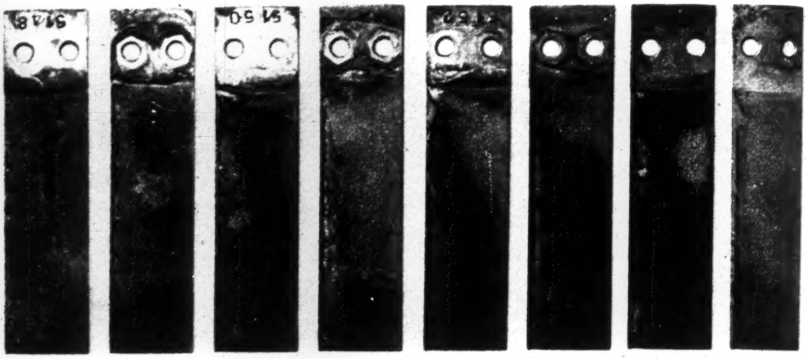
In view of the excellent resistance of 10 per cent cupro-nickel containing sub-



Iron, per cent	0.003	0.51	0.77	1.04	0.80	0.01	0.04	0.48	0.51
Manganese, per cent	0.19	0.18	0.18	0.20	0.12	0.27	0.62	0.77	0.27
Nom. Nickel, per cent	10	10	10	10	10	30	30	30	30
Analysis Reference No.	19	22	23	24	34	35	36	37	38
Max. Depth of Corrosion, in.	0.010	0.004	0.000	0.000	0.000	0.000	0.001	0.000	0.000

FIG. 8.—10 and 30 per cent Cupro-Nickels on Horizontal Shaft Impingement Tester.—Run No. 28.

3 per cent sea salt solution, temperature = 100 F. Peripheral velocity 48 ft. per sec. Duration of test = 8 weeks. Leading edge on right.



Iron, per cent	0.005	0.10	0.25	0.50	0.75	1.01	1.52	0.77[a]
Manganese, per cent	0.08	0.09	0.08	0.08	0.09	0.08	0.09	0.18
Nom. Nickel, per cent	2	2	2	2	2	2	2	10
Analysis Reference No.	39	40	41	42	43	44	45	23
Max. Depth of Corrosion, in.	0.009	0.009	0.008	0.008	0.007	0.007	0.007	0.005

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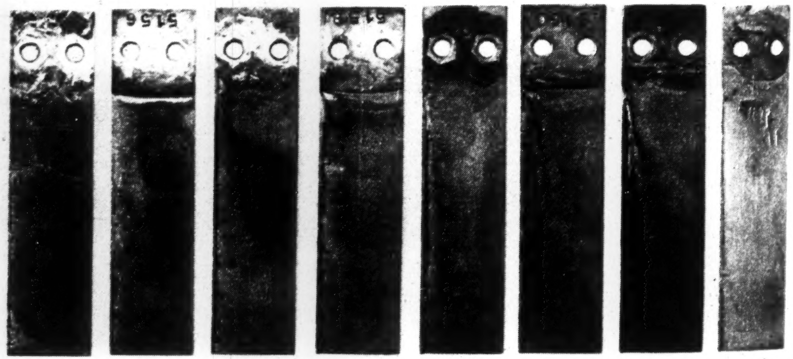
[a] 10 per cent cupro-nickel for comparison.



Iron, per cent	0.005	0.10	0.26	0.49	0.76	1.00	91.4	0.06[b]
Manganese, per cent	0.08	0.09	0.09	0.09	0.09	0.10	0.07	0.76
Nom. Nickel, per cent	5	5	5	5	5	5	5	30
Analysis Reference No.	46	47	48	49	50	51	52	8
Max. Depth of Corrosion, in.	0.008	0.008	0.008	0.006	0.007	0.005	0.006	0.009

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[b] 30 per cent cupro-nickel for comparison.

FIG. 9.—2 and 5 per cent Cupro-Nickel Series on Vertical Shaft Impingement Tester—Run No. 29.

3 per cent sea salt solution, room temperature. Peripheral velocity 20 ft. per sec. Duration of test = 4 weeks. Leading edge on left.

stantial amounts of iron, tests were made to determine the effect of iron in amounts up to 1½ per cent on the corrosion resistance of the 2 per cent and 5 per cent cupro-nickels when exposed to sea-salt solution at high velocity. For comparison, a 10 per cent cupro-nickel containing 0.75 per cent iron and a 30 per cent cupro-nickel substantially free from iron were included. The test was made with one specimen of each alloy on the vertical-shaft impingement tester and the specimens had a peripheral velocity of 20 ft. per sec. The test was run for only 4 weeks. The results of this test are shown in Table VII, Figs. 9 and 18.

TABLE VII.—2 AND 5 PER CENT CUPRO-NICKELS TEST ON VERTICAL-SHAFT IMPINGEMENT TESTER —RUN NO. 29 AT 20 FT. PER SEC. FOR 4 WEEKS, ROOM TEMPERATURE.

	Analysis Reference Number	Penetration, in.					Remarks
		At Point *A*	At Point *B*	At Point *C*	At Point *D*	Maximum	
2% cupro-nickel, 0% iron	39	0.009	0.004	0.004	0.003	0.009	No visible film
2% cupro-nickel, 0.10% iron	40	0.009	0.004	0.004	0.004	0.009	
2% cupro-nickel, 0.25% iron	41	0.008	0.003	0.004	0.002	0.008	
2% cupro-nickel, 0.50% iron	42	0.008	0.007	0.002	0.000	0.008	Traces of greenish film on two thirds of area
2% cupro-nickel, 0.75% iron	43	0.007	0.002	0.002	0.000	0.007	
2% cupro-nickel, 1.00% iron	44	0.007	0.002	0.002	0.000	0.007	Traces of greenish film near low velocity end of specimen
2% cupro-nickel, 1.50% iron	45	0.007	0.001	0.003	0.001	0.007	Thin, almost black film on one half of area
5% cupro-nickel, 0% iron	46	0.008	0.004	0.005	0.002	0.008	No visible film
5% cupro-nickel, 0.10% iron	47	0.008	0.004	0.005	0.003	0.008	
5% cupro-nickel, 0.25% iron	48	0.008	0.004	0.003	0.001	0.008	Traces of greenish film
5% cupro-nickel, 0.50% iron	49	0.006	0.002	0.001	0.000	0.006	Triangle of thin, grayish film out from low velocity end covering one third of area
5% cupro-nickel, 0.75% iron	50	0.007	0.002	0.000	0.000	0.007	Brown film on three quarters of area
5% cupro-nickel, 1.00% iron	51	0.005	0.001	0.001	0.000	0.005	Brown film except just in back of leading edge
5% cupro-nickel, 1.50% iron	52	0.005	0.001	0.001	0.001	0.006	Dark brown film except just in back of leading edge
10% cupro-nickel, 0.75% iron	23	0.005	0.001	0.001	0.000	0.005	Thin brown film except just in back of leading edge
30% cupro-nickel, 0.06% iron	8	0.009	0.006	0.006	0.004	0.009	No visible film

At Points *A* and *B* (1/16 in. from outer edge) velocity = 20 ft. per sec.
At Points *C* and *D* (1/16 in. from supporting disk) velocity = 12 ft. per sec.
Points *A* and *C* on leading edge.
Points *B* and *D* on trailing edge.

The addition of iron up to 1.5 per cent to the 2 per cent and 5 per cent cupro-nickels has only slightly reduced the maximum thinning, but has tended to reduce the average over-all corrosion. More definite results might have been obtained in a longer test.

Run No. 32—Copper, 2, 5, 10, 20, and 30 per cent Cupro-Nickels:

In order to have a direct comparison of the effect of iron on the several copper-nickel alloys, a test was made on the vertical-shaft impingement tester on the following series using one specimen of each metal or alloy:

Copper, no added iron and 0.87 per cent iron.

2 per cent cupro-nickel, no added iron, 0.75 per cent iron, and 1.01 per cent iron.

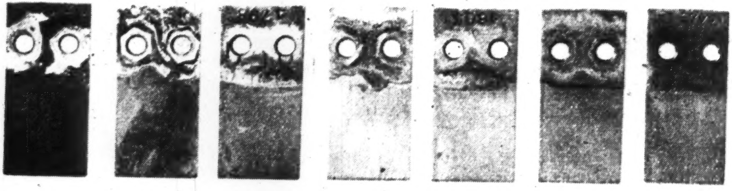
5 per cent cupro-nickel, no added iron, 0.75 per cent iron, and 1.00 per cent iron.

10 per cent cupro-nickel, no added iron and 0.77 per cent iron.

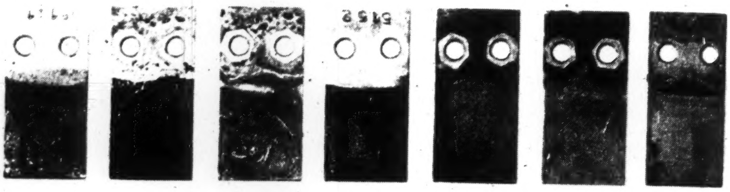
20 per cent cupro-nickel, no added iron and 0.77 per cent iron.

30 per cent cupro-nickel, no added iron and 0.50 per cent iron.

Specimens in this test were 2 by 1 by 0.040 in. and had a maximum velocity



Iron, per cent	0.003	0.87	0.005	0.75	1.01	0.005	0.76
Manganese, per cent	0.09	0.09	0.08	0.09	0.08	0.08	0.09
Nom. Nickel, per cent	0	0	2	2	2	5	5
Analysis Reference No.	53	54	39	43	44	46	50
Max. Depth of Corrosion, in.	0.005	0.005	0.005	0.004	0.005	0.005	0.004



Iron, per cent	1.00	0.003	0.77	0.003	0.77	0.06	0.50
Manganese, per cent	0.10	0.19	0.18	0.28	0.28	0.76	0.78
Nom. Nickel, per cent	5	10	10	20	20	30	30
Analysis Reference No.	51	19	23	26	30	8	13
Max. Depth of Corrosion, in.	0.002	0.004	0.003	0.006	0.000	0.006	0.000

FIG. 10.—Copper, 2, 5, 10, 20, and 30 per cent Cupro-Nickels on Vertical Shaft Impingement Tester —Run No. 32.

3 per cent sea salt solution, room temperature. Peripheral velocity 10 ft. per sec. Duration of test = 8 weeks. Leading edge on left.

TABLE VIII.—COPPER, 2, 5, 10, 20, AND 30 PER CENT CUPRO-NICKELS TEST ON VERTICAL-SHAFT IMPINGEMENT TESTER—RUN NO. 32 AT 10 FT. PER SEC. FOR 8 WEEKS, ROOM TEMPERATURE.

	Analysis Reference Number	Penetration, in.					Remarks
		At Point *A*	At Point *B*	At Point *C*	At Point *D*	Maximum	
Copper 0% iron	53	0.005	0.003	0.004	0.001	0.005	No visible film
Copper 0.87% iron	54	0.005	0.003	0.004	0.002	0.005	Blackened with trace of green film near low velocity end
2% cupro-nickel, 0% iron	39	0.005	0.002	0.003	0.002	0.005	No visible film
2% cupro-nickel, 0.75% iron	43	0.004	0.001	0.002	0.001	0.004	Discontinuous greenish film except back of leading edge
2% cupro-nickel, 1.00% iron	44	0.004	0.000	0.001	0.000	0.005	Green film except just back of leading edge
5% cupro-nickel, 0% iron	46	0.005	0.002	0.003	0.002	0.005	No visible film
5% cupro-nickel, 0.75% iron	50	0.004	0.000	0.001	0.000	0.004	Thin, light green film except just back of leading edge
5% cupro-nickel, 1.00% iron	51	0.002	0.000	0.001	0.000	0.002	Dark gray-green film except just back of leading edge
10% cupro-nickel, 0% iron	19	0.004	0.002	0.003	0.002	0.004	No visible film
10% cupro-nickel, 0.75% iron	23	0.002	0.001	0.000	0.000	0.003	Light green film
20% cupro-nickel, 0% iron	26	0.006	0.003	0.004	0.003	0.006	No visible film
20% cupro-nickel, 0.75% iron	30	0.000	0.000	0.000	0.000	0.000	Light green film
30% cupro-nickel, 0.06% iron	8	0.006	0.004	0.005	0.003	0.006	No visible film
30% cupro-nickel, 0.50% iron	13	0.000	0.000	0.000	0.000	0.000	Bright green film

At Points *A* and *B* (1/16 in. from outer edge) velocity = 10 ft. per sec.
At Points *C* and *D* (1/16 in. from supporting disk) velocity = 8 ft. per sec.
Points *A* and *C* on leading edge.
Points *B* and *D* on trailing edge.

of 10 ft. per sec. The duration of the test was 8 weeks. The results are given in Table VIII, Figs. 10 and 19. In this test the resistance of copper to impingement type of corrosion in sea water was not affected by 0.87 per cent iron. In general, iron additions had an increasing effect on corrosion resistance as the nickel content was increased.

TESTS ON HORIZONTAL-SHAFT IMPINGEMENT TESTER

Run No. 28—10 and 30 per cent Cupro-Nickel Series:

Run No. 28 was made on the horizontal-shaft impingement tester shown in Fig. 3. The peripheral velocity of the specimens was 48 ft. per sec., and the duration of the test was 8 weeks. As stated previously, the sea-salt solution in this testing apparatus was whipped full of air bubbles as the specimens whirled in and out of the solution. The condition of the tested specimens is shown in Fig. 8. The individual thickness measurements are given in Table VI and the maximum depths of corrosion are shown in Fig. 17. The rapid corrosion of 10 per cent cupro-nickel substantially free from iron; the definite effect of iron additions on this alloy; and the low loss of all the 30 per cent cupro-nickels are of particular significance. It will be recalled that the test specimens shown in Fig. 6 for run 24 on the vertical-shaft impingement tester indicated that iron-free 10 per cent cupro-nickel was corroded less than iron-free 30 per cent cupro-nickel. In run 28 where the turbulence was greater and quantities of air bubbles were present, the iron-free 10 per cent cupro-nickel was corroded much more than iron-free 30 per cent cupro-nickel. It may be that iron-free 10 per cent cupro-nickel is more resistant under conditions of lower oxygen content, while the corrosion resistance of iron-free 30 per cent cupro-nickel is definitely improved by the presence of air bubbles in the solution. Chapman and Cuthbertson[6] have expressed the thought that ordinary 30 per cent cupro-nickel requires highly aerated sea water to form a good protective film. The most important consideration, however, is the good effect of iron additions to cupro-nickel as shown in the results from both types of tests.

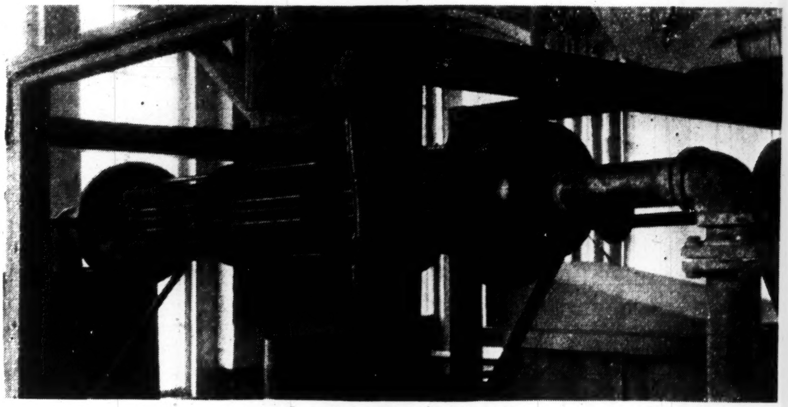


FIG. 11.—Experimental Condenser.

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[6] J. Chapman and J. W. Cuthbertson, "The Corrosion-Resisting Properties of Bronze Condenser Tubes—II Electrode Potential Time Relationships," *Journal*, Soc. Chem. Ind. (British), Vol. LVIII, No. 11, pp. 330–334, 1939.

TEST IN EXPERIMENTAL CONDENSER

Further proof of the good effect of iron in 10 and 20 per cent cupro-nickels has been obtained in a laboratory experimental condenser[7]) which is shown in Fig. 11. Sixteen tubes, 61 in. long by $\frac{5}{8}$ in. outside diameter by 0.049 in. gage were spaced around an 8-in. circle in Everdur tube plates. Two glass tubes of similar size were placed just outside the 8-in. circle in diametrically opposite positions so that the turbulence and aeration along the length of the tube could be observed. Extreme turbulence, shown by air-bubble paths, apparently

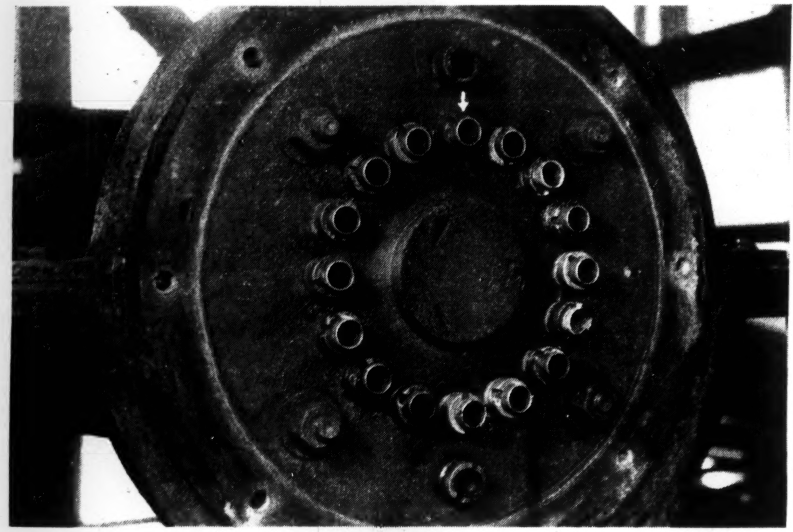

FIG. 12.—Inlet Ends of Tubes in Experimental Condenser After Seven Months of Test.

Starting at arrow going counterclockwise the tubes are:

1. 10 per cent cupro-nickel, 0.80 per cent iron.
2. 10 per cent cupro-nickel, 0.80 per cent iron.
3. 30 per cent cupro-nickel, 0.07 per cent iron.
4. 30 per cent cupro-nickel, 0.45 per cent iron.
5. 10 per cent cupro-nickel, 0.80 per cent iron.
6. 10 per cent cupro-nickel, 0.80 per cent iron.
7. 10 per cent cupro-nickel, 0.05 per cent iron.
9. 10 per cent cupro-nickel, 0.80 per cent iron.
10. 10 per cent cupro-nickel, 0.80 per cent iron.
12. arsenical admiralty, 0.03 per cent arsenic.
13. 10 per cent cupro-nickel, 0.80 per cent iron.
14. 10 per cent cupro-nickel, 0.80 per cent iron.
15. Aluminum brass (Ambraloy 927)

TABLE IX.—TUBES TESTED IN EXPERIMENTAL CONDENSER.

	Tubes Tested	Analysis Reference Number	Method of Manufacture	Condition After 7 months of Test
No. 1	10% cupro-nickel, 0.80% iron	34	Extruded	No visible end corrosion
No. 2	10% cupro-nickel, 0.80% iron	34	Pierced	
No. 3	30% cupro-nickel, 0.07% iron	55	Extruded	Slight end corrosion; longitudinal striations
No. 4	30% cupro-nickel, 0.45% iron	56	Extruded	No visible end corrosion
No. 5	10% cupro-nickel, 0.80% iron	34	Extruded	
No. 6	10% cupro-nickel, 0.80% iron	34	Pierced	
No. 7	10% cupro-nickel, 0.05% iron	57	Extruded	Roughened on end, inside wall corroded and undercut just beyond end
No. 9	10% cupro-nickel, 0.80% iron	34	Extruded	No visible end corrosion
No. 10	10% cupro-nickel, 0.80% iron	34	Pierced	
No. 12	Arsenical admiralty, 0.03% arsenic	58	Extruded	End corroded back ¼ in. Ring of pits 2 in. from inlet
No. 13	10% cupro-nickel, 0.80% iron	34	Extruded	No visible end corrosion
No. 14	10% cupro-nickel, 0.80% iron	34	Pierced	
No. 15	Aluminum brass (Ambraloy 927)	59	Extruded	Roughened on end, but better than admiralty

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[7] John R. Freeman, Jr., and A. W. Tracy, "The Relative Corrosion of Some Condenser Tube Alloys." Unpublished report to Am. Soc. Mech. Eng., Special Research Committee on Condenser Tubes, 1932.

extended only about 6 in. along the tubes from the inlet end. A 3 per cent solution of Turk's Island sea salt, such as used in the impingement tests, was circulated through the tubes by a centrifugal pump at a rate of 8 to 10 ft. per sec. The friction of the salt water solution flowing through the system raised the temperature of the solution about 30 F. above room temperature. The solution was circulated from a 40-gal. Everdur tank through red brass piping so there were no iron parts in contact with the test solution.

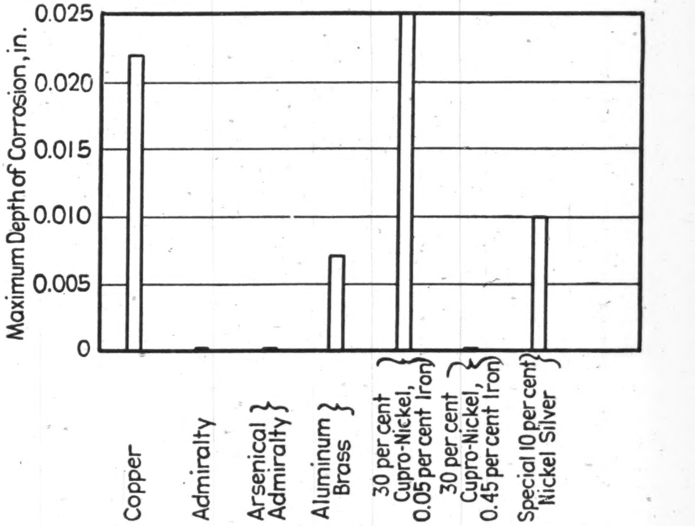

FIG. 13.—Run No. 12—Tests on Vertical Shaft Impingement Tester.
3 per cent sea salt solution at room temperature. Velocity = 8 ft. per sec. Duration of test = 26 weeks.

Figure 12 shows the inlet ends of the tubes after a 7-month test in the experimental condenser. It can be observed that the tubes extended ¼ in. beyond the ends of the ferrules, which themselves extended ¼ in. beyond the face of the tube plate. This position of the inlet ends was a condition which encouraged impingement corrosion since stream-line flow into the tubes was virtually impossible. The alloys of significance to this report are described in Table IX. The analysis reference numbers again refer to numbers in Table I, giving the compositions by analysis.

Under the particular conditions of test in this experimental condenser, the several alloys would be rated as follows:

30 per cent cupro-nickel plus 0.45 per cent iron—best
10 per cent cupro-nickel plus 0.80 per cent iron
30 per cent cupro-nickel no added iron
10 per cent cupro-nickel no added iron
Aluminum brass
Admiralty

The good corrosion resistance of 30 per cent cupro-nickel with no added iron confirmed the test results in the horizontal-shaft impingement tester, and gave support to the theory that low-iron 30 per cent cupro-nickel requires the presence of oxygen to form a good protective film in sea water.

CONCLUSIONS

These tests show quite conclusively the effect of iron content in improving

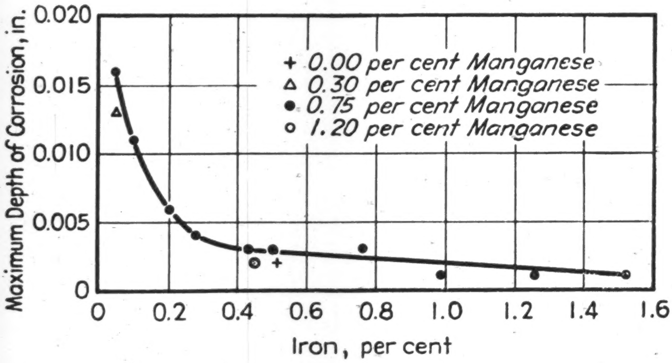

FIG. 14.—Run No. 25—30 per cent Cupro-Nickel Tests on Vertical Shaft Impingement Tester.
3 per cent sea salt solution at room temperature. Velocity = 20 ft. per sec. Duration of test = 12 weeks.

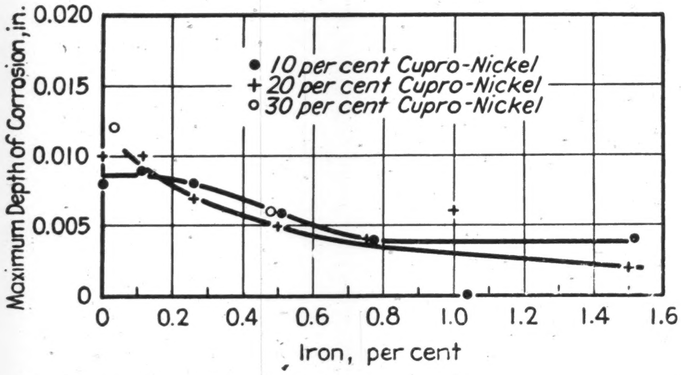

FIG. 15.—Run No. 24—10, 20, and 30 per cent Cupro-Nickel Tests on Vertical Shaft Impingement Tester.
3 per cent sea salt solution at room temperature. Velocity = 20 ft. per sec. Duration of tests = 10 weeks.

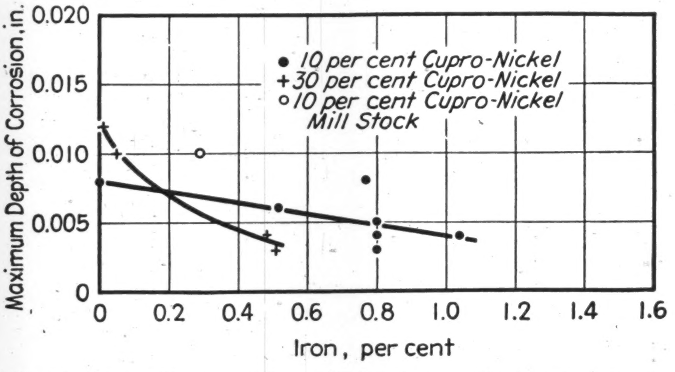

FIG. 16.—Run No. 27—10 and 30 per cent Cupro-Nickel Tests on Vertical Shaft Impingement Tester.
3 per cent sea salt solution at room temperature. Velocity = 26 ft. per sec. Duration of test = 8 weeks.

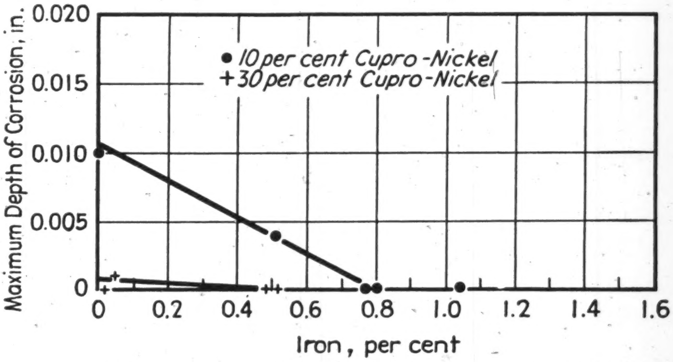

FIG. 17.—Run No. 28—10 and 30 per cent Cupro-Nickel Tests on Horizontal Shaft Impingement Tester.

3 per cent sea salt solution at 100 F. Velocity = 48 ft. per sec. Duration of test = 8 weeks.

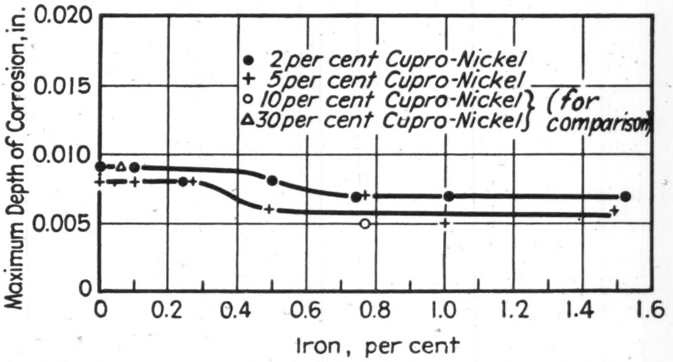

FIG. 18.—Run No. 29—2 and 5 per cent Cupro-Nickel Tests on Vertical Shaft Impingement Tester.

3 per cent sea salt solution at room temperature. Velocity = 20 ft. per sec. Duration of test = 4 weeks.

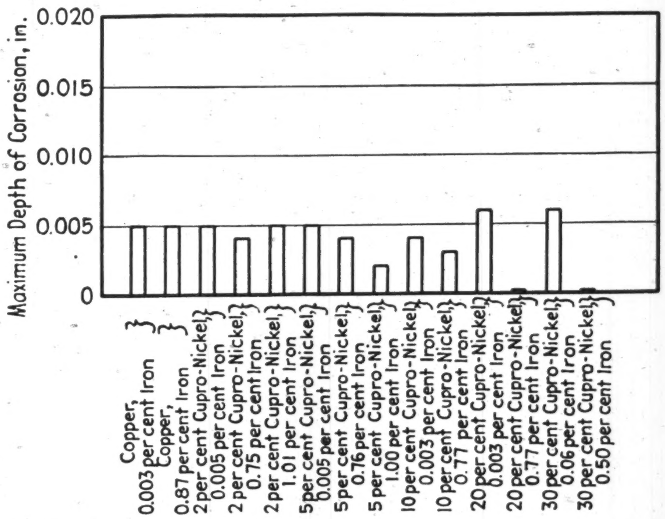

FIG. 19.—Run No. 32—Tests on Vertical Shaft Impingement Tester.

3 per cent sea salt solution at room temperature. Velocity = 10 ft. per sec. Duration of test = 8 weeks.

the resistance of cupro-nickels to impingement corrosion by sea "water". The greatest improvement in impingement corrosion resistance was imparted to cupro-nickels which had between 10 and 20 per cent nickel. The alloy with 5 per cent nickel was improved to a fair degree by the addition of iron, and the alloy with 2 per cent nickel showed some improvement when iron was added. Approximately 1 per cent iron had no effect in improving the resistance of copper to sea water impingement corrosion.

The tests indicate that as the nickel content of cupro-nickels decreases from 30 per cent to 5 per cent, more iron is required for optimum corrosion resistance; for example, 0.5 per cent iron for the 30 per cent cupro-nickel; 0.60 per cent for the 20 per cent cupro-nickel; 0.75 per cent for the 10 per cent cupro-nickel; and 1 per cent for the 5 per cent cupro-nickel.

There was no indication in these tests that a critical relationship between the iron and manganese content of cupro-nickels affected corrosion resistance.

The data tend to confirm statements in the literature that 30 per cent cupro-nickel builds a more protective film in sea water that is thoroughly aerated than in a sea water deficient in air. This may be the basis of the better service understood to be obtained from 30 per cent cupro-nickel in ships where the velocity and turbulence of the sea water is greater than in central power stations where, due to pollution of harbor waters, the oxygen content may be low.

Acknowledgment:

The work described in this paper was done under the general direction of John R. Freeman, Jr., Technical Manager of The American Brass Co.

Many of the alloys were prepared under the direction of E. W. Palmer, Research Metallurgist.

DISCUSSION*

MR. C. L. BULOW[1] (*by letter*).—The paper by Messrs. Tracy and Hungerford indicates that the addition of iron to cupro-nickel is beneficial under the conditions existing in their test. We recently published[2] some results which also showed that the addition of iron to 70–30 cupro-nickel increased the corrosion resistance to clean flowing sea water (Kure Beach, N. C.).

The general agreement between tests carried out under differing conditions by at least four investigators quite definitely indicates that the addition of iron to the copper-nickel alloys is beneficial.

On the other hand, the lack of correlation of results with admiralty and aluminum brass indicates that these alloys vary appreciably in their behavior depending upon the test procedure. Apparently in Messrs. Tracy and Hungerford's test some film-destroying factor was in operation, which was not favorable to aluminum brass, but at the same time was favorable to admiralty.

MR. F. L. LAQUE[3] (*by letter*).—During the past few years we have engaged in investigations of the effects of minor constituents on the behavior of cupro-nickel alloys in sea water. To a considerable extent, these studies have paralleled those of Tracy and Hungerford and, in some instances, we have had the privilege of making tests on specimens furnished by these investigators. Our tests have been made outside the laboratory in natural sea water and, therefore, it seems worth while to present certain of our conclusions with some illustrative data to supplement those from the laboratory tests by these authors using a solution made up from sea salt.

Our original tests were made:

1. To check an opinion that the best performance of the 70–30 cupro-nickel alloy would be insured if all minor constituents were to be held to low limits, with the optimum presumably being a pure copper-nickel alloy.
2. To check conclusions of investigators for the British Non-Ferrous Metals Research Association that definite amounts of iron and manganese were desirable and to discover if the reported beneficial effects of these elements with respect to resistance to impingement attack were accompanied by any adverse effects on corrosion resistance under other conditions of exposure, as in slowly moving sea water in the presence of marine organisms.

Several 30 per cent nickel alloys covering variations in content of iron, manganese, zinc, and tin were made up and subjected to impingement tests and to immersion in slowly moving sea water at Kure Beach, N. C.

The principal conclusions from these tests were:

1. There was no benefit in achieving a pure copper-nickel alloy, since the nearest approach to such a composition was definitely inferior to the other compositions under all testing conditions, and especially with respect to resistance to impingement attack.
2. The British finding that the alloy should contain a definite amount of iron was confirmed.
3. The amount of iron needed for superior resistance to impingement attack did not impair resistance to corrosion by sea water under other conditions of exposure.

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[1] Research Chemist, Bridgeport Brass Co., Bridgeport, Conn.

[2] *Transactions*, Vol. 87, pp. 319–352, published by the Electrochemical Society (1945).

[3] In charge of Corrosion Engineering Section, Development and Research Div., The International Nickel Co., Inc., New York, N. Y.

4. Iron had its strongest effect on impingement resistance as it was increased to 0.20 per cent with a more gradual improvement as the iron content was increased further. This general effect is illustrated by the accompanying Fig. 1. Note similarity of this curve to that in Fig. 14 of the paper. Higher iron contents, at least up to 1 per cent, were found to have no detrimental effect on resistance to impingement attack or general corrosion. However, there was some evidence that in alloys that contained substantial amounts of zinc, for example, 1 per cent or more, the simultaneous presence of a high iron content tended to increase pitting under conditions of exposure to natural sea water at low velocity.

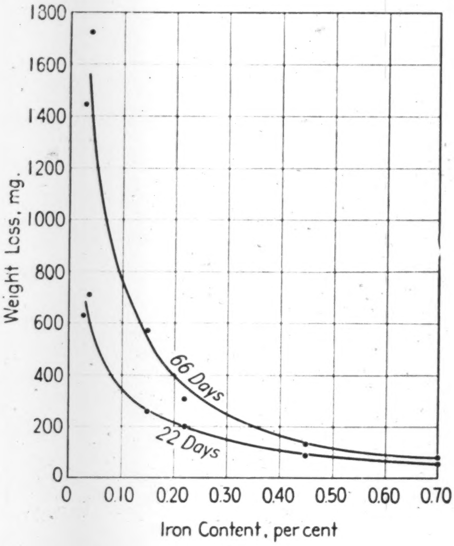


FIG. 1.—Effect of Iron Content on Erosion Resistance of 70–30 Copper-Nickel Condenser Tubes. Velocity: 20 ft. per sec. Temperature, 90 F.

5. Manganese had a generally beneficial effect, though it was less powerful than iron which it would supplement rather than replace. There was some evidence that the manganese content should exceed the iron content.

6. Zinc when present up to 2 per cent showed no important effect on resistance to impingement attack, but tended to favor pitting in natural sea water when present to the extent of 2 per cent.

7. Tin when present up to 2 per cent showed no important effect on performance under any of the testing conditions.

The effect of iron content on behavior under conditions of immersion in natural sea water is illustrated in the accompanying Table I giving the comparative data on two of the alloys studied.

TABLE I.—RESULTS OF TESTS ON CUPRO-NICKEL ALLOYS IMMERSED FOR 671 DAYS IN SEA WATER FLOWING AT 2 FT. PER SEC. AT KURE BEACH, N. C.

Alloy Composition, per cent					Average Weight Loss of 5 by 12 by 1/16-in. Specimens, g.	Depth of Deepest Attack, in.
Nickel	Copper	Iron	Manganese	Zinc		
29.5	70.4	0.006	0.05	<0.01	5.2	0.014
29.5	69.3	0.45	0.68	<0.01	2.9	0.005

TABLE II.—RESULTS OF SEA WATER IMPINGEMENT TESTS IN ASPIRATOR TYPE JET TEST APPARATUS.

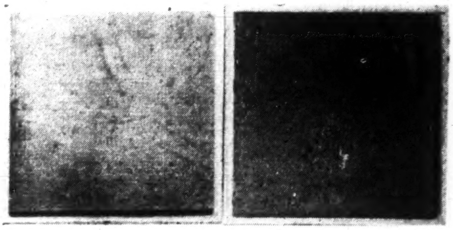
Rate of flow .... 2.7 liters per min.
Average water temperature .... 25 C.
Duration of test .... 57 days
Air bubbles mixed with water

Alloy Composition, per cent				Weight Loss, mg.	Depth of Attack, in.
Nickel	Copper	Iron	Manganese		
30.0	69.2	0.51	0.27	71	0.001
29.9	69.8	0.01	0.27	179	0.015

More recently, the resistance of the alloys to impingement attack has been studied at Kure Beach using an aspirator type of jet test apparatus. With this apparatus, a jet of sea water mixed with air bubbles (2 to 3 per cent by volume) drawn into the water as it passes through the jet is made to impinge on the flat surface of a specimen placed just in front of the jet. The effect of iron content on the behavior of 70–30 cupro-nickel under such testing conditions is illustrated by the data in Table II.

The difference between the two alloys is shown even more strikingly by the accompanying Fig. 2 showing the appearance of the specimens after this jet test.

Tests on the 70–30 cupro-nickel which contained only 0.01 per cent iron at different jet velocities and in the presence and absence of entangled air bubbles in the jet (Table III) showed that as the severity of impingement attack conditions was reduced, and especially when air bubbles were absent, this alloy would demonstrate excellent resistance to such attack. The appearance of a specimen of this alloy after tests at a lower flow rate and in the absence of added air bubbles is shown in the accompanying Fig. 3, which should be compared with Fig. 2 of the same alloy after exposure to more severe testing conditions.



70–30 Cu-Ni with 0.5 per cent Fe

70–30 Cu-Ni with 0.01 per cent Fe

FIG. 2.—70-30 Copper-Nickel Alloys After Exposure in Aspirator Type Sea Water Jet Test at Flow Rate of 2.7 Liters per Minute with Air Bubbles Present at 25 C.

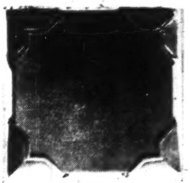


FIG. 3.—70–30 Cupro-Nickel Alloy Containing 0.01 per cent Iron After Exposure in Aspirator Type Sea Water Jet Test at Flow Rate of 1.8 Liters per Minute with No Air Bubbles Present at 25 C.

The relatively good performance of the low iron content alloy under these particular testing conditions was in line with the fact that a very large tonnage of low iron content 70–30 cupro-nickel is performing very well in service under conditions where impingement attack might be expected. From this, it would appear that many of the testing conditions chosen for the study of these alloys are much more severe than those normally encountered. At the same time, since the higher-iron content alloy performs well throughout a wide range of severity of exposure conditions, it would be prudent to choose this alloy for services where the severity of the impingement attack conditions is unknown or where very severe conditions are expected.

Unfortunately, the behavior of the low-iron content alloy in these tests with and without air failed to confirm some of the indications of tests by Tracy and Hungerford that the low-iron content alloy performs best when the water is thoroughly aerated. Probably the effect of air is tied in with other factors that were not the same in their tests and ours. Some further investigations now in progress, and to be made, are expected to throw further light on this interesting phase of the subject.

TABLE III.—RESULTS OF TESTS SHOWING EFFECTS OF JET VELOCITY AND AIR BUBBLES ON IMPINGEMENT ATTACK OF LOW IRON 70–30 CUPRO-NICKEL.

Duration of test—67 days.

Rate of Discharge of Sea Water From Jet, liters per min.	Weight Loss, mg.		Depth of Attack, in.	
	Air Bubbles Mixed With Water	No Air Bubbles in Water	Air Bubbles Mixed With Water	No Air Bubbles in Water
2.7	535	....	0.006	......
1.8	180	167[a]	0.007	0.001[a]

[a] Admiralty brass tested under the same conditions at the same time suffered a weight loss of 454 mg. and attack to a depth of 0.015 in.

We also have tested alloys of lower nickel content which contained added iron and can confirm the finding that these compositions possess excellent resistance to corrosion and impingement attack in sea water.

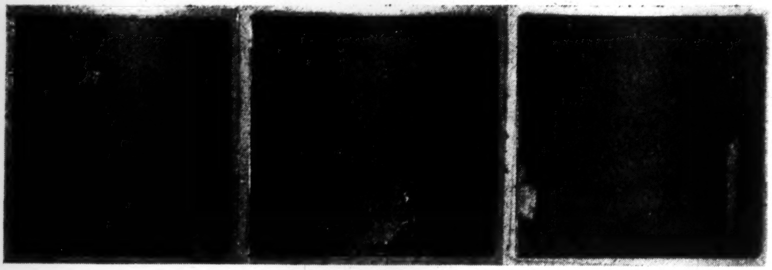
Typical results of tests with the

aspirator type of jet apparatus are given in Table IV.

The appearance of the 70–30 cupro-nickel alloy after test is shown in Fig. 2 and of the 10 per cent nickel alloy and the brasses in the accompanying Fig. 4.

Specimens of the low-nickel content alloy also were exposed immersed in slowly moving sea water at Kure Beach with results given in Table V.

It would appear from our tests and those of Tracy and Hungerford that the iron-modified cupro-nickel alloys containing from 10 to 12 per cent nickel are equal or superior to many of the older compositions now employed to resist attack by sea water.



10 per cent cupro-nickel with 0.8 per cent Fe | Admiralty brass | Aluminum brass

FIG. 4.—Specimens After Exposure in Aspirator Type Sea Water Jet Test at Flow Rate of 2.7 Liters per Minute with Air Bubbles Present at 25 C.

TABLE IV.—RESULTS OF JET TESTS AT FLOW RATE OF 2.7 LITERS PER MINUTE WITH AIR BUBBLES PRESENT AT 25 C.

Alloy Composition, per cent							Weight Loss, mg. per day	Maximum Depth of Attack, in. per month
Nickel	Copper	Iron	Manganese	Zinc	Aluminum	Arsenic		
10.0	89.0	0.8	0.2	....	...	....	3.6	0.003
30.0	69.2	0.5	0.3	....	...	....	1.8	0.0006
....	70.7	0.02	...	28.1	...	0.03[a]	15.5	0.009
....	76.4	0.07	...	21.5	2.0	0.06[b]	5.4	0.0015

[a] Admiralty brass.
[b] Aluminum brass.

TABLE V.—RESULTS OF IMMERSION TESTS OF CUPRO-NICKEL ALLOYS AT KURE BEACH, N. C.

Alloy Composition, per cent				Duration of Exposure, days	Weight Loss, mg. per sq. dm. per day	Maximum Depth of Attack, in.
Nickel	Copper	Iron	Manganese			
12.6	Bal.	0.30	0.43	987	2.9	0.005
12.6	Bal.	1.8	0.43	987	1.9	0.011
30	70	...	...	987	2.6	0.010
10.0	89.0	0.8	0.2	357	2.8	...
29.4	69.4	0.4	0.8	357	4.2	...
30.4	69.0	0.05	0.3	357	7.0	...
Arsenical admiralty brass.....				357	16.8	...
Arsenical aluminum brass.....				357	4.2	...

It is evident, also, that the laboratory testing techniques used by Tracy and Hungerford provide satisfactory means of evaluating the ability of copper alloys to resist erosion or impingement attack in sea water.

MR. G. L. BAILEY[4] (*by letter*).—This paper is extremely interesting to us because we ourselves have been doing a great deal of work on similar alloys during the last seven years. The work of my colleague, Mr. May, on the effect of iron and manganese on the resistance of 70–30 cupro-nickel alloys in sea water, which is quoted by the authors, opened the door to wider investigations on the effect of these constituents on copper-nickel alloys of lower nickel content. We have explored a wide range of nickel and iron contents and can confirm the authors' findings as to the effect of iron on the resistance of copper-nickel alloys to corrosion-erosion or impingement attack, particularly in the range 5 to 10 per cent nickel, which we have studied most fully. We agree that manganese is far less effective but should make it clear that the relationship we found between manganese and iron content in the 70–30 alloy applied with very low iron contents. If the iron content is sufficiently high, 0.5 per cent or more, resistance of the alloys to sea water corrosion under conditions of air bubble impingement seems to be independent of the manganese content.

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[4] Director, British Non-Ferrous Metals Research Association, London, England.

Our methods of testing have differed considerably from those employed by the authors: We have based most of our conclusions on the results of the jet test of the type described by Mr. May[5], and have used a wide variety of samples of natural sea water. The nature of the water used is of very considerable importance. Experiments we have made with sea salt have generally given us a more widespread and shallower type of attack than we consider normal for natural sea water, perhaps owing to the absence of organic contamination when redissolved sea salt is used. The difference in behavior of a particular alloy when tested in natural waters with different degrees of such contamination can be very considerable, and we think experiments based only on the results of tests in a solution of sea salt will not line up with service behavior as well as could be desired.

It is, however, very satisfactory to find that despite differences of technique, the authors have obtained results which in essence are similar to ours. Service trials of the low-nickel iron-bearing alloys are far from complete in this country, but the evidence that is available is encouraging, and it is hoped that with the termination of the war it will be possible to present our information for publication.

One important result of the authors is not in agreement with our findings, namely, the relatively poor resistance of aluminum brass reported in Fig. 13. It is very surprising to us to see aluminum brass more attacked in such a test than admiralty metal and we feel there is something amiss with this particular test, the results of which are at variance with an immense amount of laboratory and service experience.

MESSRS. A. W. TRACY AND R. L. HUNGERFORD (*authors' closure by letter*).—The authors appreciate the discussions offered by Messrs. Bulow, LaQue, and Bailey and are gratified that our laboratory test results agree in so large a measure with their tests on copper-nickel alloys.

Messrs. Bulow and Bailey point to the poor showing of aluminum brass compared to admiralty as indicated by our data and state that this fact does not agree with their experience. It should have been emphasized in the paper that the more rapid attack on aluminum brass was rather unexpected. We have made many other comparative tests on the impingement resistance of admiralty and aluminum brass and are convinced that aluminum brass is in general superior to admiralty in this respect.

The information furnished by Mr. LaQue based on his tests at Kure Beach, N. C. is an important contribution to the value of the paper under discussion.

Mr. Bailey's observation that experiments made with sea salt solutions may not line up with service behavior in natural sea water is well taken. Although tests made in sea salt solutions will apparently agree quite well with those made in clean sea water at Kure Beach, they might not agree in every respect with tests made in polluted harbor water. We would all agree that the actual value of an experimental alloy could only be finally decided by a service test.

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[5] R. May, "Eighth Report of Institute of Metals Corrosion Committee," *Journal*, Inst. Metals, Vol. 60, pp. 141–185 (1928).

OBSERVATIONS ON THE APPEARANCE WELDING OF MALLEABLE CASTINGS

By H. A. Schwartz,[1] Ira Young,[1] and James Hedberg[1]

Introduction

> "Fusion welding of malleable iron is not recommended for stress-carrying parts because of the resultant formation of a brittle structure. There are applications, however, where tensile stresses are low or stresses are compressive only, in which welded malleable irons, even though lower in ductility and impact value at the weld, may be employed."
> —*American Malleable Iron—A Handbook, Malleable Founders' Society, Cleveland, Ohio, p. 60 (1944).*

This paper concerns itself exclusively with the repair, by welding, of surface defects. No expression of opinion is intended on any matter involving welds to sustain important working stresses. Within the limitations of this paper, such welds need be ductile enough to permit of very moderate deformation and soft enough to permit machining at speeds comparable with those used on malleable iron. We propose to use deflection in cross bending as a test for ductility and indentation hardness as a measure of machinability. The latter is a matter of practical necessity, for no machine shop would be willing to make observations on tool life on materials known in advance to be inferior. Reference to commercial machining on welds made by a promising technique will follow in due course.

A very brief discussion of the techniques of welding malleable castings has been published by the American Welding Society.[2]

There is a general belief, receiving considerable support by the work here reported, that the ideal method of welding consists in the use of white cast iron as a filler material, followed by a subsequent complete malleable annealing treatment.

The Welding Hand Book is not very clear on what type of "annealing" is to follow welding with soft steel. A complete malleable anneal is presupposed in some quarters, though there seems to be reason to doubt its necessity.

This paper is intended to illustrate, in the light of ductility, hardness measurements and metallography, the results to be expected from various welding techniques. Such detailed comparisons seem to be lacking in the literature, hence were deemed useful by Committee A-7 on Malleable-Iron Castings.

Experimental Procedure

Test specimens were prepared from a single lot of malleable iron. They were $1\frac{1}{4}$ by $\frac{1}{2}$ in. in cross-section and about 8 in. long. A $\frac{3}{4}$-in. drill hole was made approximately half way through the specimen to an exact depth, and these holes were welded by experienced opera-

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[1] Manager of Research, Engineer of Tests, and Research Assistant in the Research Department, respectively, National Malleable and Steel Castings Co., Cleveland, Ohio.

[2] *Welding Handbook*, p. 849 (1942).

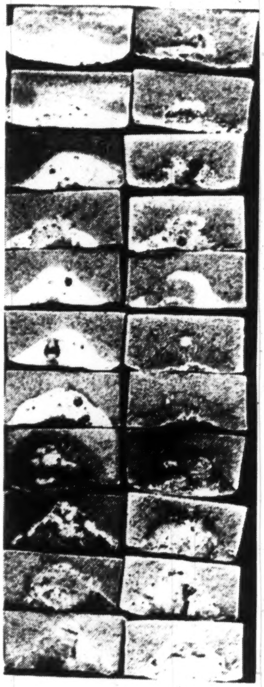
Heat treatment, $1\frac{3}{4}$ hr. at 1280 F. and quenched.
Acetylene welded with hard iron.
Acetylene welded with hard iron.
Arc welded with hard iron.
Arc welded with hard iron.
Arc welded with gray iron.
Arc welded with gray iron.
Arc welded with gray iron.
Arc welded with soft steel.
Arc welded with soft steel.
Arc welded with Monel metal.
Arc welded with Monel metal.
Heat treatment, full malleable anneal.
Acetylene welded with hard iron.
Acetylene welded with hard iron.
Arc welded with hard iron.
Arc welded with hard iron.
Arc welded with gray iron.
Arc welded with gray iron.
Arc welded with gray iron.
Arc welded with soft steel.
Arc welded with soft steel.
Arc welded with Monel metal.
Arc welded with Monel metal.

Fig. 1.—Fracture Through Welds Made by Various Techniques.

TABLE I.—DEFLECTIONS IN INCHES AT MAXIMUM LOAD OF SPECIMENS WELDED BY DIFFERENT TECHNIQUES AND OPERATORS.

Second Heat Treatment	Welder	Full Re-anneal	$1\frac{3}{4}$ hr. at 1280 F. and Quenched
Acetylene welded, hard iron filler		0.44	0.12
Carbon arc weld	A	0.33	0.06
Hard iron filler	B	0.19	0.06
Average		0.26	0.06
Carbon arc weld	A	0.36	0.05
Gray iron filler	B	0.19	0.04
Average		0.28	0.05
Arc weld	A	0.16	0.07
Soft steel filler	B	0.17	0.07
Average		0.17	0.07
Arc weld	A	0.19	0.21
Monel filler	B	0.37	0.46
Average		0.28	0.39

tors, using various techniques. In the case of the arc-welded material, two different operators performed the same operation. In the case of the gas-welded material, only one.

Five specimens prepared by each technique by each electric welder were completely re-annealed in the Dressler kiln, running on a commercial cycle at the Cleveland Works of the National Malleable and Steel Castings Co., and five others were merely held $1\frac{3}{4}$ hr. at 1280 F. and cooled at any convenient rate.

In the case of the gas-welded specimens, nine and ten specimens, respectively, were given these same heat treatments. The specimens were broken in cross bending on supports $7\frac{1}{2}$ in. apart. Since we are not interested in the exact comparisons of strength, it did not seem worthwhile to attempt any refinements of the irregular surfaces sometimes left by the welder. The deflection at maximum load was recorded for each specimen and averaged (separately if the work was that of two different welders). The welding techniques and the corresponding deflections are summarized in Table I.

It is plain from the table that good deflections are obtainable best by acetylene welding with hard iron and fully re-annealing, and by arc welding with Monel metal and tempering.

Typical fractures through the welds are shown in Fig. 1. In general, several welds of the same type are here photographed. It will be seen that in a few cases the weld separated from the body of the metal, but usually the fracture was through the weld itself.

Having in mind the obvious desirability of doing away with the long-time heat treatment of fully re-annealing, similar specimens were prepared by arc welding with soft steel and with Monel metal. The steel welds were either given the normal malleable anneal or the 1¾-hr. tempering at 1280 F., and the Monel welds were given either the latter heat treatment or they were held 8 hr. at 1320 F. and cooled in 12 hr. to 1200 F. These specimens had the welded surface finished by surface grinding and were then macroetched to develop the weld boundary. Rockwell hardness readings were then taken along a weld diameter in order to measure the hardness distribution more accurately than was possible on cross-sections of the specimens prepared for the cross-bending test.

Micrographs shown in Figs. 2 to 20 inclusive, were taken in various regions deemed appropriate in the cross-bending specimens.

Figure 21 is an additional micrograph obtained from the second series of welds which were made for the purpose of exploring the hardness distribution in certain welds made by techniques involving a short heat treatment.

DISCUSSION OF DATA

When a malleable casting is welded, obviously the filler material must have been raised to the melting point, and equally obviously the temperature of the parent metal must have been substantially at or above the melting point of the filler material where it abuts on the weld itself, and the maximum temperature must have graded off to room temperature in some distance, not necessarily known, back from the weld metal. Keeping this distance small is probably one of the skills of the welder.

Now it will be obvious that that portion of the malleable iron nearest the weld which has been raised to a temperature above the critical point, will have carbon re-combined. Any portion which has been re-melted will have reverted to white cast iron. If the filler material is also white cast iron, it seems plausible that a malleable anneal, applied to the whole structure, will make everything go back to the condition of malleable iron. One would, therefore, expect a malleable iron casting, welded with hard iron and re-annealed, to have, throughout, the properties of ordinary malleable iron. This is, in fact, approximately true.

The micrographs indicate that malleable iron annealed twice, once before and once after welding, and also the hard iron welded into malleable, annealed once, have substantially the normal malleable iron structure except that in the transition zone between the weld and parent metal there is a somewhat peculiar and rather flaky graphite distribution, irrespective of whether the welding was by the acetylene flame or the carbon arc.

Gray iron deposited as weld metal, and no doubt freezing nearly as white cast

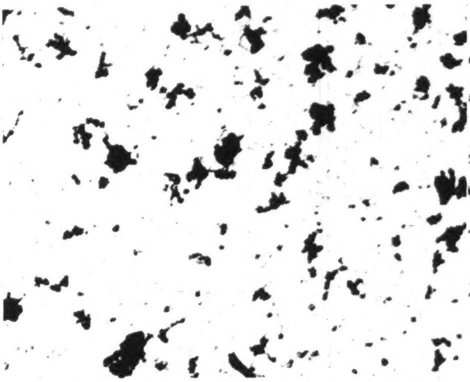

FIG. 2.—Malleable Iron After a Second Complete Anneal (× 100). Etched in picric acid.

FIG. 3.—Hard Iron Weld Metal Deposited by Acetylene Welding After a Complete Re-anneal (× 100). Etched in picric acid.

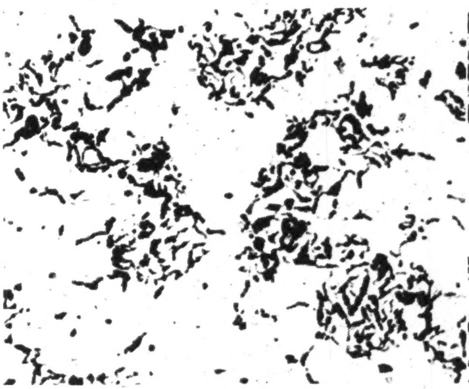

FIG. 4.—Transition Zone Between Malleable Iron and Hard Iron Weld Metal Deposited by Acetylene Welding After a Complete Re-anneal (× 100). Etched in picric acid.

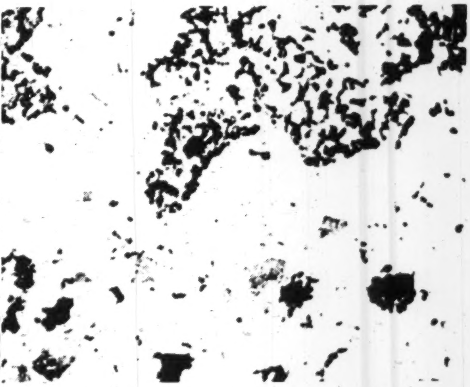

FIG. 5.—Transition Zone Between Malleable Iron and Hard Iron Weld Metal Deposited by the Carbon Arc After Complete Re-anneal (× 100). Etched in picric acid.

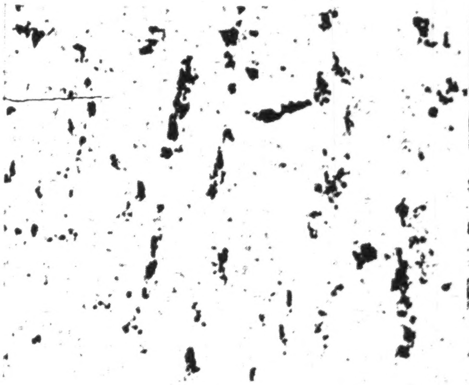

FIG. 6.—Transition Zone Between Gray Iron Deposited by Carbon Arc Welding and Malleable Iron After Complete Re-anneal (× 100). Etched in picric acid.

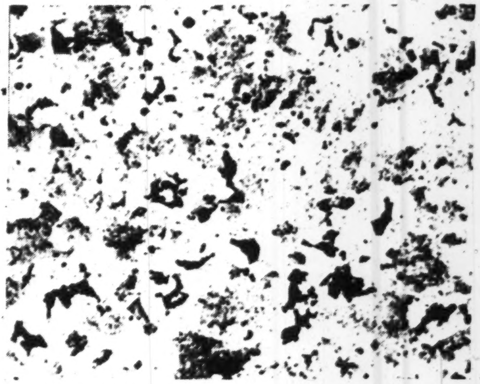

FIG. 7.—Malleable Castings About 0.1 in. Away from a Soft Steel Arc Weld, Incompletely Annealed on Subsequent Re-anneal (× 100). Etched in picric acid.

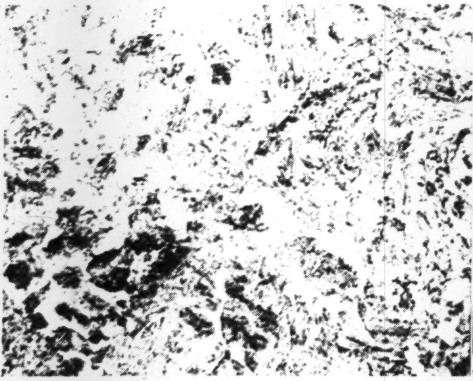

FIG. 8.—Portion Near the Zone of Contact of Soft Steel Deposited by Arc Welding in Malleable Iron. Complete Re-anneal (× 100). Etched in picric acid.

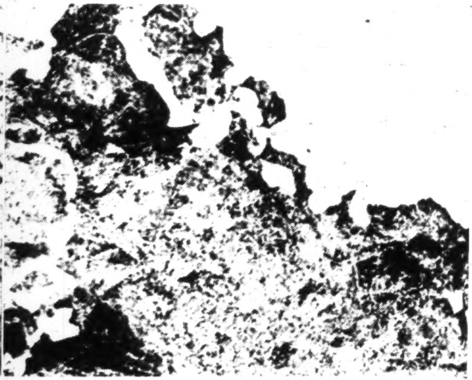

FIG. 9.—Zone of Contact Between Soft Steel Deposited by Arc Welding in Malleable Iron and the Parent Metal After Complete Re-anneal (× 100). Etched in picric acid.

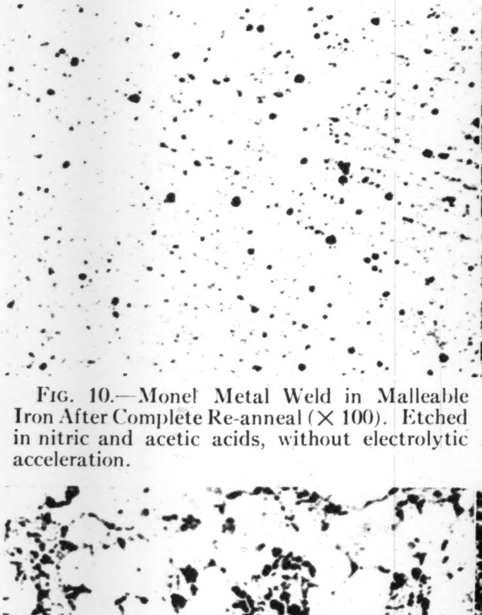

FIG. 10.—Monel Metal Weld in Malleable Iron After Complete Re-anneal (× 100). Etched in nitric and acetic acids, without electrolytic acceleration.

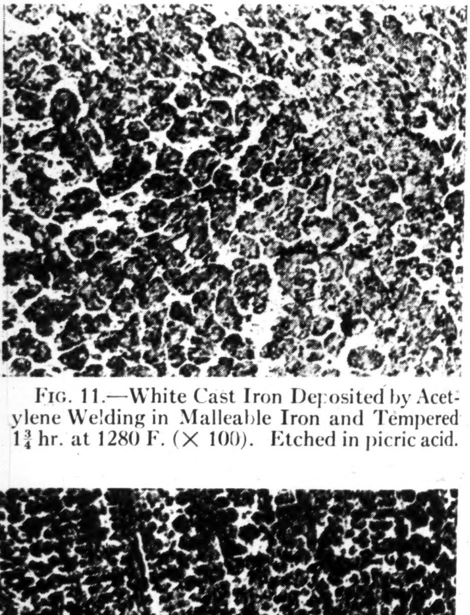

FIG. 11.—White Cast Iron Deposited by Acetylene Welding in Malleable Iron and Tempered $1\frac{3}{4}$ hr. at 1280 F. (× 100). Etched in picric acid.

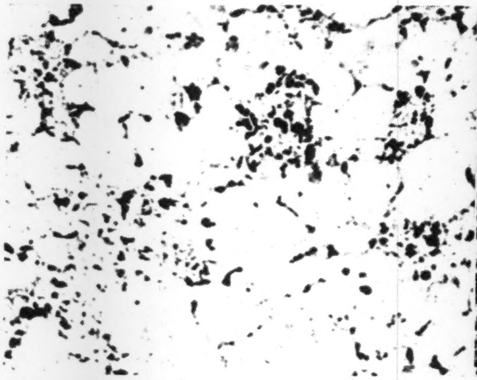

FIG. 12.—Transition Zone Between Hard Iron Deposited by Acetylene Welding in Malleable Iron and the Malleable Iron After Heat Treating $1\frac{3}{4}$ hr. at 1280 F. (× 100). Etched in picric acid.

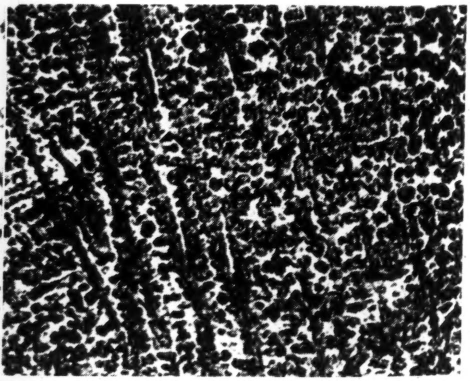

FIG. 13.—White Cast Iron Deposited by Arc Welding in Malleable Iron and Tempered $1\frac{3}{4}$ hr. at 1280 F. (× 100). Etched in picric acid.

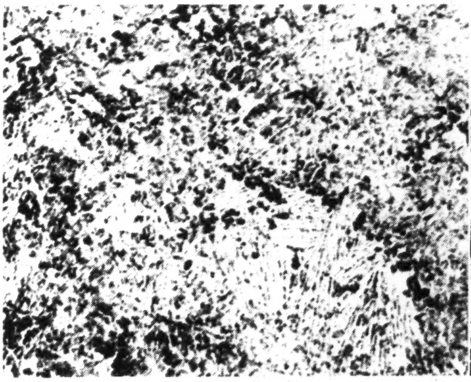

FIG. 14.—Zone Near the Border Between Malleable Iron and White Cast Iron, Deposited by Arc Welding. Tempered 1¾ hr. at 1280 F. (× 100). Etched in picric acid.

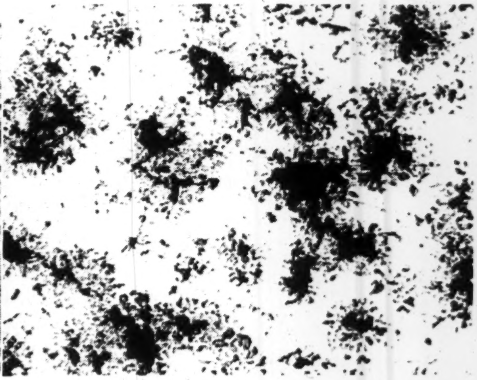

FIG. 15.—Zone in Malleable Iron 0.1 in. Away from Hard Iron Deposited by Arc Welding. Tempered 1¾ hr. at 1280 F. (× 100). Etched in picric acid.

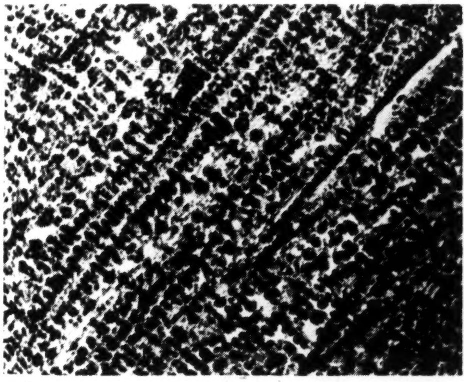

FIG. 16.—Gray Iron Deposited by Arc Welding in Malleable Iron. Tempered 1¾ hr. at 1280 F. (× 100). Etched in picric acid.

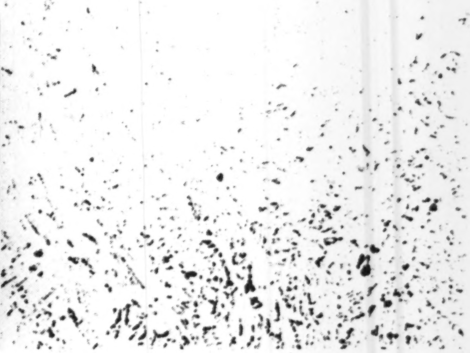

FIG. 17.—Transition Zone Between a Soft Steel Arc Weld and the Parent Malleable Iron. Tempered 1¾ hr. at 1280 F. (× 100). Etched in picric acid.

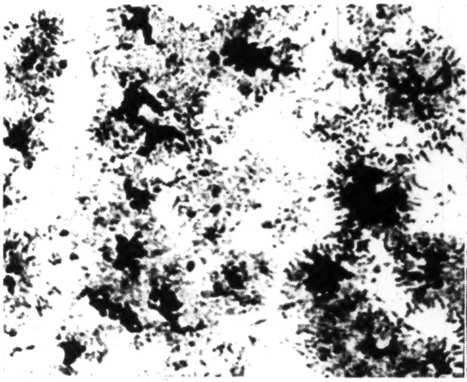

FIG. 18.—Malleable Iron Slightly Away from Soft Steel Arc Weld. Tempered 1¾ hr. at 1280 F. (× 100). Etched in picric acid.

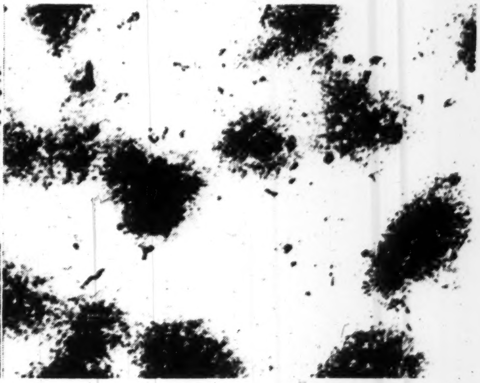

FIG. 19.—Malleable Iron Slightly Away from Monel Metal Arc Weld. Tempered 1¾ hr. at 1280 F. (× 100). Etched in picric acid.

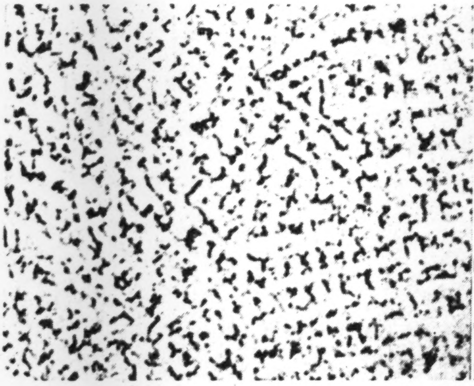

FIG. 20.—Monel Metal Arc Weld in Malleable Iron. Tempered 1¾ hr. at 1280 F. (× 100). Etched in nitric and acetic acids, without electrolytic acceleration.

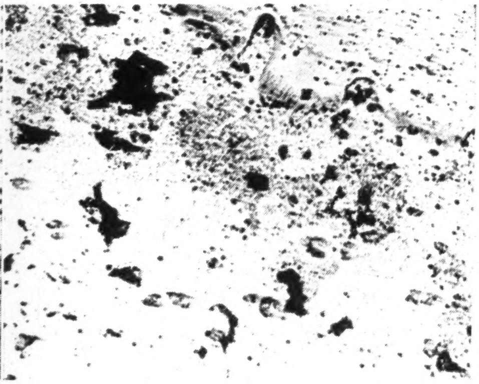

FIG. 21.—Transition Zone Between Malleable Iron and Monel Metal Arc Weld. Heated 8 hr. at 1320 F. and cooled in 12 hr. to 1200 F. (× 100). Etched in picric acid.

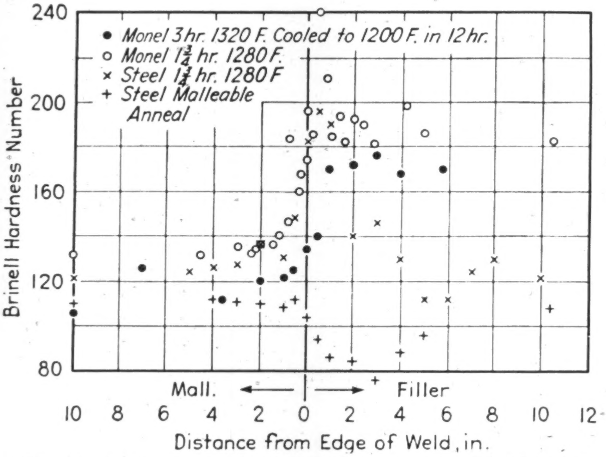

FIG. 22.—Hardness Distribution in Steel and Monel Metal Arc Weld in Malleable Iron After Various Tempering Treatments.

iron, is converted by the malleable anneal to ferrite and graphite, but some of the latter is in rather stringy form. There seems to be some tendency for steel welds to cause the retention of combined carbon in the annealing heat treatment even at some distance away from the weld, as shown in Fig. 7, which is similar to an ordinary bull's eye malleable. At the zone of contact between malleable iron and steel, the latter absorbs carbon from the parent metal. The presence of nearly pure ferrite next to the weld structure in Fig. 9 is peculiar.

Monel metal, like steel, seems to favor the retention of some combined carbon at some distance away from the weld. There seems, however, to be no evidence of diffusion between the iron base and the nickel copper alloy. Work still in progress seems to show that welding with nickel produces results similar to those obtained with Monel metal.

If the heat treatment is limited to tempering, white iron filler material remains apparently unaltered.

In the transition zones re-melted malleable iron also sometimes shows some reversion to white cast iron, and even 0.1 in. away from the weld some recombination of carbon can be observed. Similar statements could be made with regard to gray cast iron used as the filler material.

Soft steel welds show in the transition zone some carbon pick-up in the steel and some recarburization of malleable iron near the weld. The same may be said of Monel metal welds given the short tempering heat treatment. However, if these welds are tempered at 1320 F., then the slowly cooled transition zone is limited to a narrow band of partly spheroidized pearlite.

It seems rather unnecessary to discuss in detail the hardness in the various typical fields illustrated by the micrographs. Obviously where the structure is malleable iron, the hardness has not been much changed except to the extent that all malleable iron, when quenched from below the A_1 temperature, say 1280 F., shows some hardening not connected with the recombination of carbon. The white cast iron structures are, of course, intensely hard, and the structures which are steel-like in character, have approximately the hardness of steels of similar microstructure.

Steel welds are acceptable to some machine shops with only a tempering treatment. The Monel welds are obviously better than steel from the viewpoint of microstructure; supported also by hardness observations not here reported in detail. It was for this reason that the second series of welds was made and explored as to hardness across the diameter of the weld.

The Brinell numbers as calculated from "B" Rockwell readings, averaged for a number of welds of each type, are summarized in Fig. 22, which is no doubt self explanatory. It may be said for comparison that the standard practice of gas welding with white cast iron and reannealing would have yielded Brinell readings from 97 to 121, and averaging about 100 or 110, entirely across the weld and reaching indefinitely each way into the parent metal.

As a check on the validity of the argument that Monel welds tempered $1\frac{3}{4}$ hr. at 1280 F. should machine satisfactorily, a considerable series of sample welds were machined in a production shop, using Carboloy tools, and cutting at their normal machining speeds for malleable iron. This operation was conducted by a corporation not connected with the National Malleable and Steel Castings Co., who reported that the machining was entirely satisfactory.

CONCLUSIONS

It has not been the purpose of this paper to draw any conclusions presenting great novelty to those who may have worked with the welding of malleable castings. The purpose has been to indicate the microstructure which might be expected from various techniques and to investigate those techniques involving a short post heat treatment in comparisons with the more established practice of welding with hard iron completely reannealed. The viewpoint has been mainly to determine whether such welds are sufficiently machinable and ductile to be a satisfactory means of improving the appearance of malleable castings. The authors conclude from the evidence presented that such is the case.

Acknowledgments:

The authors are indebted to J. J. Kanter and J. H. Lansing, who, with the senior author, constituted the temporary subcommittee on welding of Committee A-7 for reviewing our results. Mr. Lansing suggested the last Monel heat treatment discussed in the paper.

The photographs, with the exception of Fig. 21, are the work of Evelyn Halpern, formerly Metallographer in the Research Department of the National Malleable and Steel Castings Co.

DISCUSSION

Mr. C. H. Lorig[1] (*by letter*).—The information on welding of malleable castings reported by Schwartz, Young, and Hedberg, while still preliminary, is indeed interesting. It is hoped this work will continue so that considerably more data are secured regarding the influence of variations in welding techniques and the metallurgy of welds. Little if any information of this nature is as yet available.

The great strides made in the welding of steels, and the successes in welding which have followed developments in electrode coatings suggest that fusion welding of malleable iron is not inherently impossible. By applying some of the welding techniques for steel and using specially coated electrodes designed specifically for malleable iron, there are reasonable possibilities that successful welding of malleable iron can be achieved. Coatings made to contain certain alloying elements or combinations of elements might well be found that will give weld deposits that are not only satisfactory from the standpoint of soundness and properties, but that also respond quickly to low-temperature heat treatments.

The increased hardness in and back from the fusion zone in the base metal resulting from heating above the transformation temperature during welding offers the major obstacle to overcome in fusion welding of malleable iron. It would seem possible, however, through an intensive study of the problem that rather simple means could be found to regulate the hardness increase, perhaps, by control of the weld process itself so as to keep the carbon absorption to a minimum, or by diffusing into the highly-heated zone of the base metal constituents which accelerate greatly graphitization at low temperatures.

The problem of welding malleable iron is not simple. Its practical solution is likely to require an enormous amount of work. Yet the repair and salvaging of malleable castings, if it could be achieved readily by welding, is of profound interest to the malleable industry. It is hoped, therefore, that the work of obtaining satisfactory welds in malleable iron will continue.

Mr. G. Vennerholm[2] (*by letter*).—This paper is of particular interest in that it helps to dispel the stigma that has surrounded the repair welding of malleable iron in the past and is a step towards placing the repair welding of malleable iron in the same category as repair welding of steel, which for years has been an established procedure.

The results published by the author concur with the experience of the writer in that satisfactory results can be obtained by either welding with a similar material, that is, white iron followed by complete re-anneal, or by welding with a dissimilar material as, for example, non-ferrous followed merely by a low-temperature treatment of about 1300 F. In addition to the methods described in the paper, high- and low-temperature brazing has found widespread application in the repair of minor defects where little or no post heat can be applied.

It is of interest to note that the recommended procedures under the "Repair of Malleable Iron Castings" issued by the S. A. E. War Engineering Board, embody the general outline of the present paper.

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[1] Supervising Metallurgist, Battelle Memorial Inst., Columbus, Ohio.

[2] Ford Motor Co., Dearborn, Mich.

MR. A. R. LYTLE[3] (*by letter*).—The repair of malleable iron castings has always presented an interesting metallurgical problem on welding because the unique nature of malleable iron has made it impossible, even under the most favorable conditions, to reproduce in a welded member the same properties possessed by the original material. It is well known, and confirmed by the data in the present paper, that the closest approach to this is obtained in castings that have been remalleableized after welding by the acetylene flame, using welding rods of white iron composition. In such welds, the weld metal malleableizes satisfactorily, but in a narrow band of base metal adjoining the weld metal, the graphite exists in flake form, which reduces the ductility of the assembly. It is therefore reasonable for many purposes to avoid involved heat treatments altogether and to resort to what the authors term "appearance welding." The object of this, of course, is to repair an obvious defect in a way that is the simplest to perform and has the least deleterious effect on the malleable iron.

The authors have made two series of tests, using both arc- and flame-welding methods. One series of welded castings was subjected to the standard malleableizing treatment, and in the other series the welded castings were heated to 1280 F. for $1\frac{3}{4}$ hr. and quenched, a treatment intended to render the iron immune from embrittlement during subsequent heating operations. The results of the deflection tests and metallographic examination clearly show that none of the welds with ferrous welding rods produced acceptable physical properties and microstructures when given only this latter heat treatment. This is undoubtedly due to the formation of hard constituents that were not transformed by the heat treatment. Under these conditions it would seem that, for the acetylene welds, a welding rod of gray iron composition might have been a better choice, because such a rod is designed to produce graphite iron in the deposit, while, as the photomicrographs in the paper show, white iron was formed in the acetylene welds. Welded specimens prepared with the gray iron rods should give higher results in the deflection test. The deflection test results of the specimens electric-welded with monel rod are considerably superior to those of specimens made with ferrous rods. Undoubtedly the high bend values obtained were due to the higher ductility of the weld metal rather than to the absence of heat effect on the base metal. It would be interesting to learn the effect of the size of the casting on the heat effect adjacent to the monel metal arc weld. With heavier base metal the heat effect might be more pronounced.

The series would have been more complete if bronze-welded specimens had been included. As bronze-welding is done at temperatures just above the AC_1 critical point, only a moderate amount of re-solution of carbon occurs. There is, therefore, no formation of flake graphite nor of white iron constituents on cooling. This holds true for both large and small weld repairs. Moreover the ferrite ground mass offers an especially receptive surface for the bronze weld metal. The yellow color of the bronze would generally not be objectionable, as most metal articles are painted or otherwise surface-treated. Nickel bronzes are available which match the color of malleable iron quite closely. These characteristics have made bronze-welding the leading method of repair of malleable iron, as pointed out in the American Welding Society Welding Handbook.

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[3] Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

MR. H. A. SCHWARTZ (*author's closure by letter*).—To the author it seems that the problem of preventing hardness in malleable welds is the problem of limiting the thickness of the layer between weld metal applied above the critical point and that layer in the malleable iron which just did not reach the critical point. Apparently this is a matter of putting in heat so rapidly that it does not have time to diffuse away from the weld zone. It would seem difficult to imagine the addition of a graphitizing agent so effective as to produce second-stage graphitization in the very short time available during cooling, and sufficiently able to migrate into the heat-affected zone of the malleable iron so that it was present in effective amounts clear to the depth to which a temperature equivalent to the A_1 temperature has penetrated. It is possible that such a solution exists. It would supposedly be a little easier to do this where post heat was used, as in some of the present experiments, so that no such terrific acceleration of second-stage graphitization rate is required as would be necessary to produce the graphitization during cooling.

The use of gray iron welding material seems to the writer hopeless. The present experiments were made with a commercial welding rod of this character. It must be remembered that the weld under consideration is, generally speaking, a small spot in a large chilling mass of malleable iron. We quite realize that a heavy weld can be made of gray iron without reversion to white cast iron. This does not seem to happen in any case where the welds are of such a magnitude in relation to casting's size as have seemed to be of commercial significance. If a gray iron welding rod were used and the weld were kept gray, then it would seem that we would still be confronted with the need of migrating the graphitizing agent into the heat-affected zone of the malleable iron just as discussed above.

It is not very clear why a gray iron weld, if it were on the tension side of a bend specimen, would permit of any considerable deflection. We deliberately turned our specimens in that direction so as to demonstrate whether the welds produced any useful degree of ductility. It is quite likely that many of our specimens would have had a much greater ductility had they been tested weld up. Unfortunately one cannot rely on this as an evidence of quality, since a welded area may, in service, be loaded either in tension or compression, as determined by the design, and not by the wish of the welder.

The authors are gratified at the interest shown in the paper and hope that others will be moved to improve upon what has so far been recorded.

THE CORROSION-FATIGUE PROPERTIES OF SOME HARD LEAD ALLOYS IN SULFURIC ACID[1]

By David J. Mack[2]

Synopsis

The fatigue properties of pure lead, tellurium lead, 1 per cent antimonial lead and commercial storage battery lead were determined on a rotating beam machine of the cantilever type at 1785 rpm. The endurance limits of these four materials were determined: (*a*) in air, the specimens being coated with petroleum jelly, (*b*) in 38 per cent sulfuric acid, the acid being applied to the specimens by dripping, and (*c*) in air after the specimens had been previously corroded in sulfuric acid while stress free. The endurance limits obtained in (*a*) checked many of those already reported in the literature, all tested at high speed. From the results obtained it was concluded that the corrosion-fatigue resistance of these alloys in sulfuric acid is a running balance between fatigue strength and corrosion resistance. There was good correlation between the results in (*a*) and (*c*), but not with (*b*). This shows that if the corrosion and cyclic stress occur simultaneously damage is to be expected.

The mechanism of corrosion-fatigue action in lead and lead alloys in sulfuric acid was examined. It is believed that the $PbSO_4$ film is opened up over the underlying grain boundaries by elastic deformation of the grains and by the tendency of the lead to recrystallize. This allows the acid to attack the grain boundary creating a notch. Once the notch has started, the corrosion-fatigue crack is propagated intergranularly near the surface by notch action, it being shown that lead is extremely susceptible to notch action at the speed studied. It is felt that the "breathing" action in the crack during cyclic stressing probably also contributes to the crack propagation but in a minor way. Experimental evidence is offered in support of these proposals.

With the development of the modern high-capacity lead-lead oxide storage cell it became necessary to increase the amount of active material on the plate at the expense of the amount of metal in the supporting grid. By cutting down the size of the supporting metal grid the plate becomes much more susceptible to failure by buckling, corrosion, and perhaps even creep. In the investigation of new alloys for storage battery service it was customary to determine their resistance to the sulfuric acid electrolyte by means of some type of laboratory corrosion test. What part fatigue stresses[3] and creep, either alone or in combination with corrosion from the battery acid, play in the performance of the metal grids is unknown. The fact that automotive starting battery performance tests in automobiles usually do not correlate with the performance tests of similar batteries in the laboratory suggests that corrosion-fatigue of the metal grids may be a contributing cause. The lack of similar fatigue stresses in the grids of storage batteries in stationary installations may also help to account for their long life as compared with the comparatively short-lived automobile battery, it being reasonable to expect that the effect of creep will be about the same in both cases.

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[1] This paper is part of a thesis submitted by the author to the graduate faculty at Purdue University, Lafayette, Indiana, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] Assistant Professor of Chemical Engineering, The University of Tennessee, Knoxville, Tenn.

[3] Fatigue stresses in battery grids may arise in several ways: by the motion of the plate due to external vibrations; by the expansion and contraction of the plate caused by volume changes in the active material during charge and discharge; or by expansion and contraction of the plate due to variations in temperature.

This investigation was undertaken to determine: (*a*) the reduction in fatigue strength of pure lead and several of its common alloys when corrosion in battery acid is combined with fatigue, (*b*) the straight corrosion rate of these alloys in battery acid, and (*c*) the correlation, if any, between (*a*) and (*b*). The observations made during this investigation led to an examination of the mechanism of corrosion-fatigue action of sulfuric acid on lead and lead-rich alloys. Notch sensitivity of pure lead was also studied.

THE CORROSION-FATIGUE OF LEAD—PREVIOUS WORK

The fact that lead and its alloys are extensively used for cable sheathing, a use much subject to the combined action of corrosion and fatigue has accounted for most of the published work on lead. The most extensive work has probably been done by the British Non-Ferrous Metals Research Association under Waterhouse (**7, 30**)[4] and the Engineering Experiment Station of the University of Illinois under Moore (**18, 19**). The earliest work was that of Jewett (**17**) who in 1909 studied the effect of vibration on cable sheaths of varying composition.

Several theories were advanced by the earlier workers to explain the intercrystalline cracking of lead cable sheath. Archbutt (**3**) showed that impurities in the lead were not the cause, while Rawdon (**22, 23**) disproved the idea that the "embrittlement" of lead in certain solutions was caused by an allotropic change. Apparently Beckinsale and Waterhouse (**7**) were the first to prove that the intercrystalline failure of lead cable sheath was due to fatigue. Haigh and Jones (**16**) studied the corrosion-fatigue of lead and suggested that the atmosphere, or principally its oxygen, played a very important part in the fatigue of lead and its alloys. This effect of the oxygen in the air on the fatigue of lead was proven conclusively by Gough and Sopwith (**12, 13**) who found lead to be extraordinarily susceptible to this "air-effect." They thereupon pointed out that any fatigue test of lead run in air thus becomes, in actuality, a corrosion-fatigue test. None of the above recognized that due to the presence of creep the frequency of stress cycles is a major factor affecting the endurance limit of lead as has been demonstrated by Moore and colleagues (**18, 19**).

Very little information is available on the effect of specific corrodants on the fatigue properties of lead and its alloys.

EXPERIMENTAL WORK

Materials:

In addition to commercial storage battery lead, pure lead and two of its common alloys were chosen for this investigation. The compositions of all four materials are shown in Table I. The electrolytic lead was obtained from the Eagle-Picher Lead Co. The 1 per

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[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 649.

TABLE I.—ANALYSIS OF ALLOYS USED IN CORROSION-FATIGUE STUDY.

	Element, per cent								
	Sb	As	Sn	Fe	Cu	Te	Ag	Bi	Pb
Electrolytic Lead (marked Pb)	0.004[a]	nil	...	0.0015	0.008	...	0.0003	0.0016	balance
Tellurium Lead (marked Te)	0.007	...	...	...	0.063	0.050	0.007	...	balance
Antimonial Lead (marked 1Sb)	1.005	...	...	...	...	...	...	...	balance
Storage Battery Lead (marked 9Sb)	9.36	0.047	0.434	0.0006	0.020	...	...	...	balance

[a] Includes tin.

cent antimonial lead was made by melting electrolytic lead and c.p. antimony together in a covered graphite crucible under powdered charcoal. The tellurium lead was obtained from the National Lead Co. and the storage battery lead from the Globe Battery Co.

The sulfuric acid used in the corrosion-fatigue tests was c.p. acid diluted with distilled water to a 38 per cent solution. This is a specific gravity of 1.300 corresponding to the acid concentration in a fully charged storage battery.

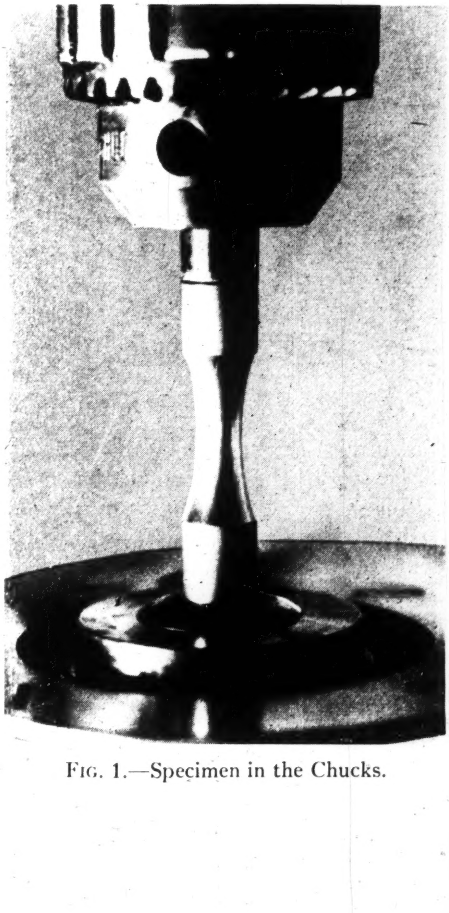

FIG. 1.—Specimen in the Chucks.

Fatigue Testing Machine:

Because of the low mechanical properties of lead, principally low tensile strength, almost negligible yield strength, and low hardness, it is a difficult material to handle in fatigue testing. These difficulties have not been sufficiently emphasized in most published work on the fatigue of lead. Its tendency to recrystallize spontaneously at room temperatures after stressing necessitates the greatest care in handling the specimens and influences the type of testing machine that can be used. A review of the literature showed that all of the fatigue tests on lead reported by the English investigators, Beckinsale and Waterhouse (7), Haigh and Jones (16), Gough and Sopwith (12, 13) had been performed on a Haigh machine (11) while some tests on a Wöhler machine (11), some on a repeated bending machine (19), and some on a rotating-beam machine of the McAdam type (28) have been described. Of these, the Haigh and Wöhler machines hold the specimens either in screw-in type chucks or by means of a locking screw, necessitating the machining of threads on the lead specimens which is a difficult job. No machine was available and the one which was finally evolved was a modified form of the canteliver beam machine with drill-type locking chucks. It was soon found, however, that these locking chucks would not grip the lead satisfactorily because of its softness, the chuck jaws biting into the lead resulting in poor alignment and allowing the specimen to work loose.

This was overcome by substituting a collet chuck at the motor, the greater area of contact between the collet and the specimen eliminating any tendency to work loose.

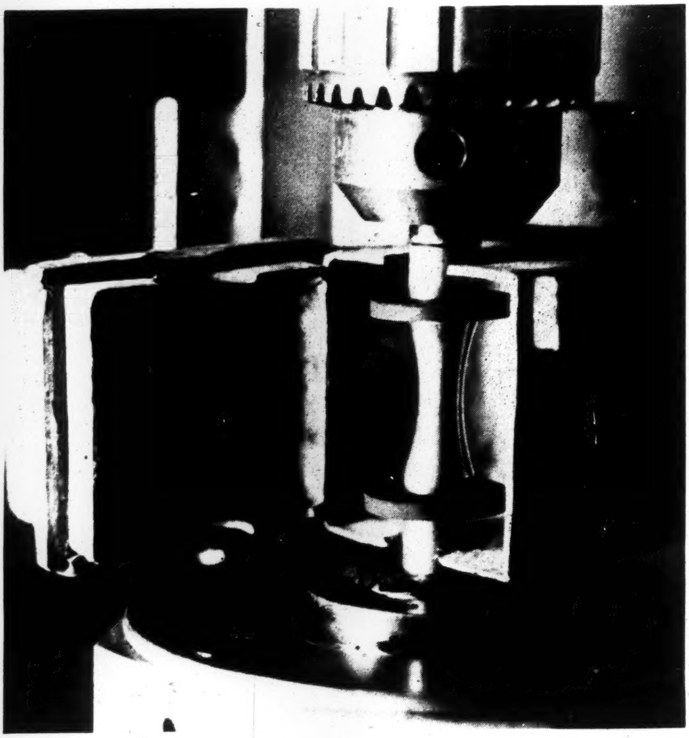

FIG. 2.—Specimen Arranged for Corrosion Fatigue Test.

The finished machine in the form in which it was used to obtain the data in this paper need not be described here. Use of a collet chuck on the floating end was not found to be feasible but it was found that the locking chuck would hold the lead specimens satisfactorily if they were fitted on that end with a press-fit split steel collar[5] (Fig. 1).

Corrosion-Fatigue Tests:

For the corrosion-fatigue tests the specimen was enclosed by a small sheet lead chamber (Fig. 2) arranged so that the sulfuric acid could be dripped onto the center of the reduced section. The acid was stored in a gallon bottle and fed to the specimen by gravity, the flow being regulated by a pinch cock to about 30 drops a minute. To keep the acid from running along the specimen and getting outside the chamber the specimen was fitted with rubber rings at each end of the reduced section (Fig. 2). After contact with the specimen the acid was drained into a bottle on the floor and returned to the storage bottle as necessary. Fresh acid was used for each alloy.

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[5] It might be expected that this circumferential contact of the grips with the specimen would give rise to an unknown stress concentration with resulting fretting action at the edge of the grip which would cause failure of the specimen at that point rather than in the reduced section. This tendency has not been observed in any of the specimens although some were run to 56,000,000 cycles. Fractures all took place in the reduced section except for defective specimens. See typical fractures in Fig. 10.

Procedure:

The alloys, excepting 1Sb, were received in the form of pigs. The pigs were chopped into small pieces with a broad face chisel and a sledge hammer. These pieces were then cleaned on all faces with a coarse file, immersed in hot 20 per cent nitric acid solution, rinsed in distilled water and dried in air. They were then immediately melted down in graphite crucibles with tight-fitting covers under a layer of powdered charcoal in a muffle type resistance furnace held at 850 F. by a Leeds & Northrup potentiometric controller. A temperature of 850 F. was chosen because it is a representative commercial casting temperature for storage battery grids (**29**). Before pouring, the alloys were drossed with a piece of charred wood and immediately cast into graphite molds at 350 F. which had been preheated in an adjoining furnace. After solidification all ingots were transferred to a drying oven where they were aged 48 hr. at 320 F. The reason for this over-aging will appear later. The 1-in. round ingots of pure lead (Pb), tellurium lead (Te), and 1 per cent antimonial lead (1Sb) were then forged down by hand to round bars $\frac{5}{8}$ in. in diameter and machined to fatigue specimens. The $\frac{3}{4}$-in. ingots of storage battery lead (9Sb) were machined directly after aging with no further treatment. The dimensions of the fatigue specmens are shown in Fig. 3. The machining of these specimens, particularly the pure lead, is a difficult problem. Because of low mechanical properties great care must be taken to avoid transverse bending of the specimen at the reduced section during preparation. This bending, if it occurs, results in nonuniform recrystallization in the reduced section resulting in unreproducible values in the fatigue test. The sequence of operation in preparing the specimens was as follows:

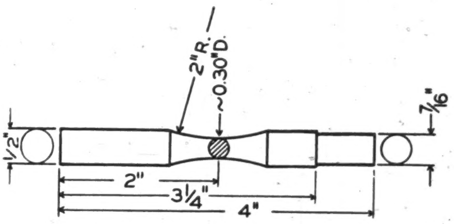

FIG. 3.—Standard Fatigue Specimen.

1. Rough machine to 0.5 + 0.02 in.
2. Cut reduced section with radius turning tool.
3. Carefully polish reduced section by hand using successively finer grades of metallographic paper with light oil.[6]
4. Finish machine ends of specimen to 0.5 in. using only very light cuts.
5. Cut to length.
6. Finish polishing reduced section with an ordinary paper towel.
7. Clean specimen in benzol.
8. Coat heavily with petroleum jelly and store in desiccator until used.

It was found impossible to machine and polish the reduced section to the same dimension on all specimens, hence the actual diameters at the reduced section (used in the computation of the stress at the outer fibers) varied from 0.300 in. to 0.330 in., and had to be determined individually for each specimen when tested.

Aging of the Alloys:

From the first endurance curves obtained, that is, those for pure lead and storage battery lead, it was obvious that apparently identical specimens of the same material prepared at different times or tested at different intervals of

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[6] Each successively finer paper was used at right angles to the preceding one. The order was so arranged that the final set of scratches ran longitudinally.

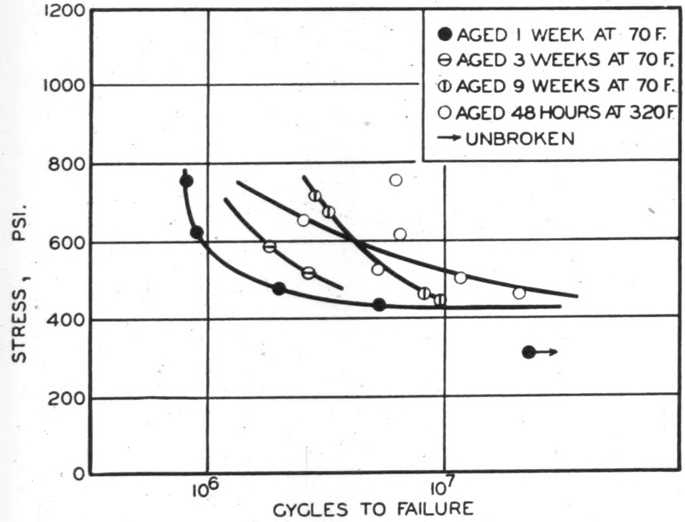

FIG. 4.—Effect of Aging on the Fatigue of Pure Lead.

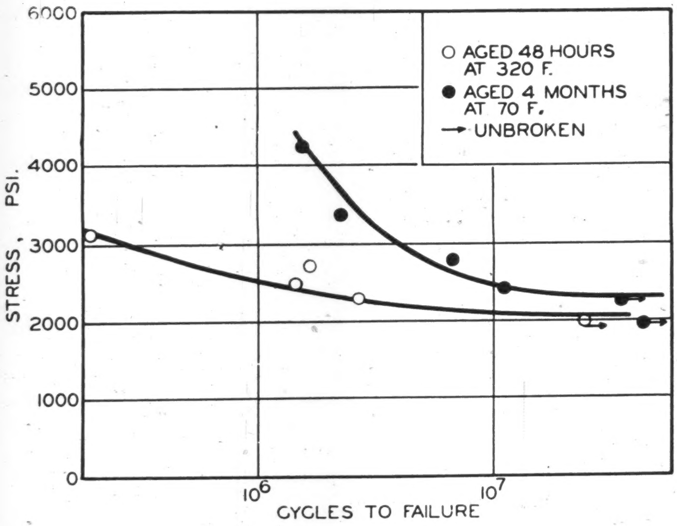

FIG. 5.—Effect of Aging on the Fatigue of Storage Battery Lead.

time after preparation gave different results (Figs. 4 and 5). This divergence may have been due to any of three causes:

1. The presence of varying amounts of impurities,

2. Nonuniform recrystallization after forging and machining, or

3. Aging effects, either as normal age hardening or as strain aging during testing.

Since all specimens of each analysis came from the same pig of material and were treated in an identical manner with due precautions to avoid any bending during machining or handling, reasons

1 and 2 seemed unlikely. Hence, it appeared that aging effects were the most probable cause of the inconsistent results, it being well known that small amounts of impurities, including dissolved gases, can cause such aging effects. An extensive investigation into the influence of impurities on the properties of lead by Greenwood, Russell, and collaborators (**14, 15, 24, 25, 26**) has shown:

1. Exceedingly small amounts of impurities, probably not exceeding 0.004 per cent, may be effective in causing age hardening in lead.

2. Vacuum cast lead is less susceptible

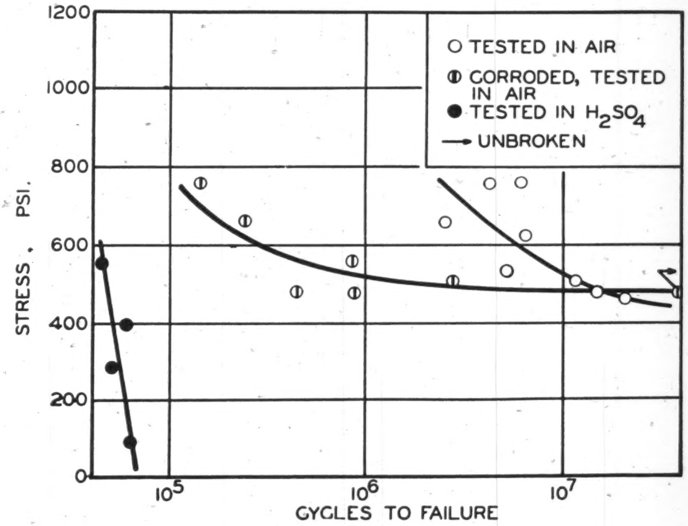

Fig. 6.—Fatigue Curves for Pure Lead.

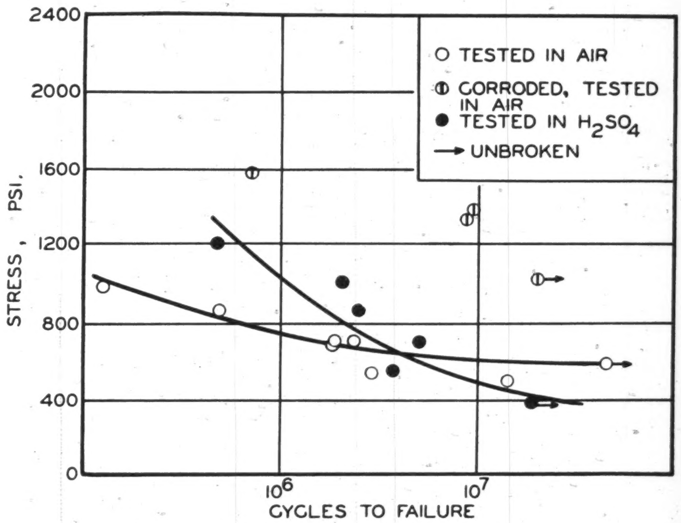

Fig. 7.—Fatigue Curves for Tellurium Lead.

to aging effects than air cast lead of the same purity.

3. Small amounts of impurities greatly restrict the recrystallization of lead after working.

4. Prior annealing at 347 F. for as little as 1 hr. also slackens the rate of recrystallization after working.

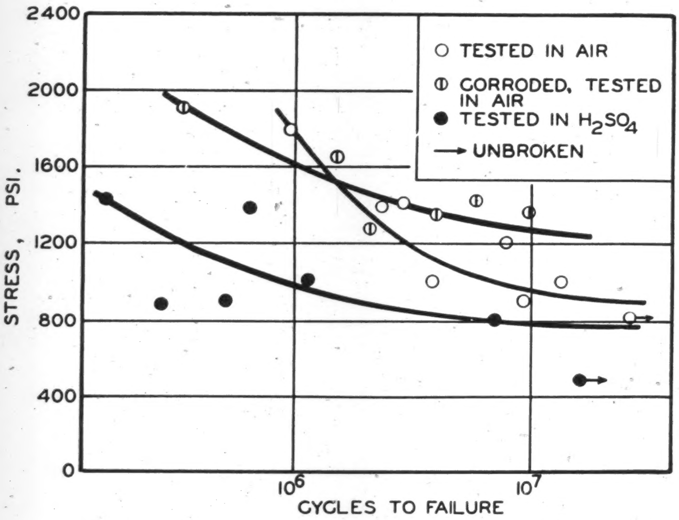

FIG. 8.—Fatigue Curves for 1 per cent Antimonial Lead.

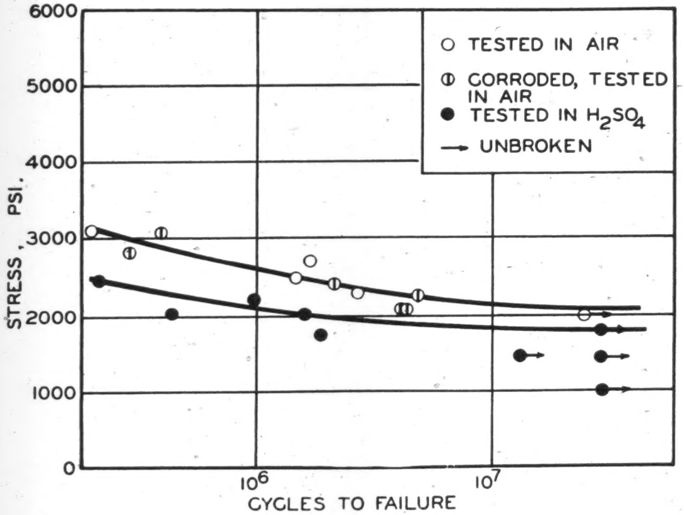

FIG. 9.—Fatigue Curves for Storage Battery Lead.

From these conclusions it seemed probable that the irregular results obtained in the first fatigue tests were due to aging effects. To counteract this irregular aging all alloys were over-aged for 48 hr. at 320 F. immediately after casting. This resulted in good reproducibility of tests on specimens from the

TABLE II.—ENDURANCE LIMITS OF SOME LEAD ALLOYS WHEN TESTED IN AIR AT 1785 RPM.

Pure lead	430 psi.
Tellurium lead	600 psi.
1 per cent antimonial lead	860 psi.
Storage battery lead	2 050 psi.

same melt run several months apart and even on specimens from different melts of the same composition, even though it does not similate the conditions under which commercial battery grids are aged.

Electrolytic Polishing:

With the publication of numerous articles dealing with electrolytic polishing (**9, 21**) of metallographic specimens, it seemed this might be an ideal method for preparing a polished surface on the reduced section of the soft lead which was difficult to produce by ordinary methods. Experiments proved that it was possible to develop a scratch-free polished surface. However, the specimens which were electrolytically polished as the final step before testing lost all resistance to fatigue and hence could not be used in this work.

RESULTS

Fatigue Tests:

The endurance limits of the four alloys when tested in air as determined from their *S-N* curves (Figs. 6 to 9) are shown in Table II. These results are consistent with endurance limits on similar alloys published by other investigators as shown in Table III.

TABLE III.—THE ENDURANCE LIMIT AS REPORTED BY VARIOUS INVESTIGATORS.

Investigator	Analysis of Lead	Treatment	Type of Machine	Speed, rpm.	Endurance Limit in Air, psi.	Reference
			PURE LEAD			
Beckinsale and Waterhouse	99.99%	rolled	Haigh	2 000	340	**7**
		extruded	Haigh	2 000	360	**7**
		extruded, annealed 1 hr. at 250 C.	Haigh	2 000	400	**7**
Dunsheath	commercially pure	extruded (?)	transverse deflection on sheet	...	400	**7**
Haigh and Jones	...	...	Haigh	2 000	430	**16**
Gough and Sopwith	99.99%	extruded	Haigh	2 000	340	**12**
Chaston	...	...	Wöhler	...	420	**8**
Townsend and Greenall	100.00%	extruded, 1 month old	McAdam	700	215	**28**
Ono	99.9914%	forged, self annealed	...	...	87.4	**20**
Unknown	pure	...	...	...	448	**10**
St. Joseph Lead Co.	commercial	...	...	700	700 (10 000 000 cycles)	**2**
	chemical (0.066% Cu)	...	...	865	725 (10 000 000 cycles)	**2**
American Smelting and Refining Co.	acid lead (0.066% Cu)	...	R. R. Moore	...	800 (10 000 000 cycles)	**1**
			ANTIMONIAL LEAD			
Beckinsale and Waterhouse	...	rolled	Haigh	2 000	1 300	**7**
	...	extruded, aged 1 hr. at 250 C.	Haigh	2 000	1 240	**7**
Townsend and Greenall	...	extruded, 1 month old	McAdam	700	300 to 450	**28**
Dunsheath	...	extruded	transverse deflection on sheet	...	1 240	**7**
St. Joseph Lead Co.	0.75% Sb	...	...	700	1200 (10 000 000 cycles)	**2**
			TELLURIUM LEAD			
Unknown	0.06% Te	...	...	...	1 142	10
St. Joseph Lead Co	0.045% Te	...	...	865	1000 (10 000 000 cycles)	2

Many of these reported results are questionable due to scatter of the points on the curves and to the fact that an insufficient number of specimens were run to define adequately the *S-N* curve, not to mention the fact that creep has an increasingly important effect on the endurance limit as the cyclic speed is reduced (**19**).

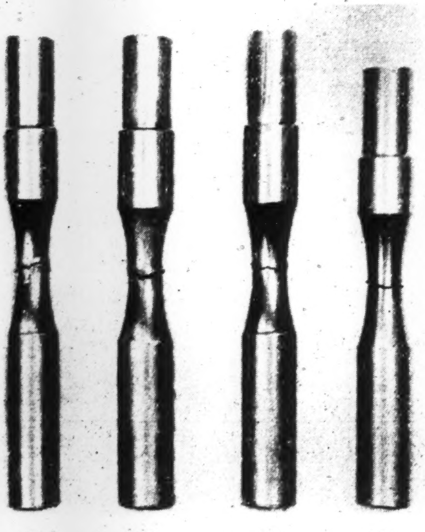

FIG. 10.—Typical Fractures.

All specimens in the present investigation broke with the characteristic "brittle" fracture as shown in Figs. 10 and 11. At high loads some plastic deformation occurred near the break. These fractures in the pure lead, tellurium lead and 1 per cent antimonial lead were intergranular in character (at least at the outer edge). In the storage battery lead the path of the fracture cut straight across the specimens (Fig. 19) and hence was probably transcrystalline.

Corrosion-Fatigue Tests:

The corrosion-fatigue limits of the four alloys in 38 per cent sulfuric acid, as determined from their *S-N* curves (Figs. 6 to 9 incl.) are shown in Table IV. The results on the pure lead seem to check the opinion held by Gough and Sopwith, McAdam and others (**4**) that

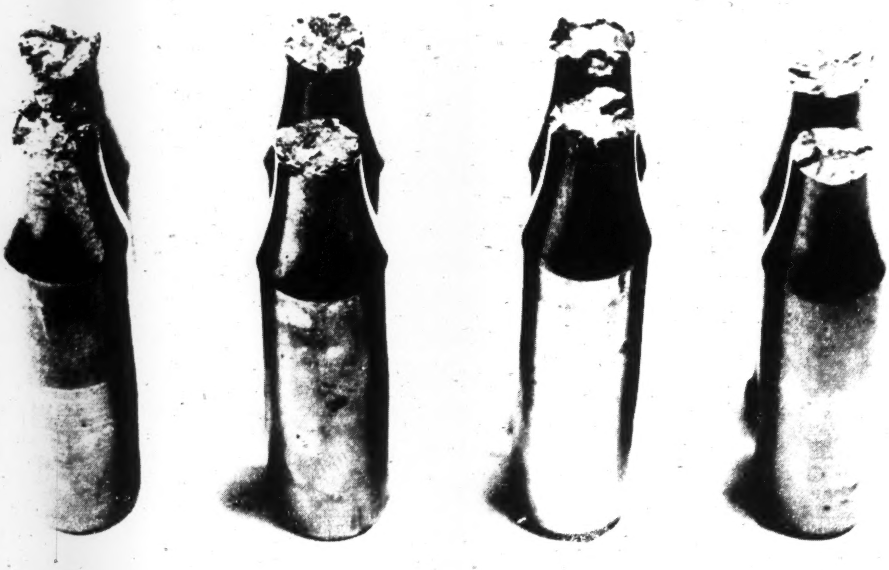

FIG. 11.—Typical Fractures Showing Grain Size.

there is no such thing as a corrosion-fatigue limit. It has been impossible to find any published data on the fatigue properties of these alloys in sulfuric acid and hence no comparison data can be offered. These fractures were also intergranular at the surface. All specimens were covered with a dull gray film of lead sulfate when removed from the machine after test.

Stressless Corrosion Tests:

The results of a stressless corrosion test in aerated 38 per cent sulfuric acid are shown in Table V. In this test, the ends of broken fatigue specimens were thoroughly cleaned and suspended on glass hooks in beakers containing 38 per cent acid. The beakers were placed in a thermostat held at 77 F. The acid in the beakers was thoroughly agitated during the entire test by means of an air jet. The specimens remained in the acid for one week. All specimens were covered with a gray lead sulfate film upon removal from the acid. It is impossible to determine corrosion rates in any kind of an immersion test with a great degree of reproducibility. The results in Table V are not to be regarded as absolute but merely as showing the relative order in which these four materials are attacked by 38 per cent sulfuric acid. Similar tests at other temperatures and in other concentrations of acid by the authors' students show these results to be typical.

TABLE IV.—CORROSION-FATIGUE LIMITS OF SOME LEAD ALLOYS TESTED IN 38 PER CENT SULFURIC ACID AT 1785 RPM.

Pure lead	0 (70 000 cycles)
Tellurium lead	400 psi.
1 per cent antimonial lead	740 psi.
Storage battery lead	1 850 psi.

TABLE V.—STRESSLESS CORROSION TESTS ON SOME LEAD ALLOYS IN 38 PER CENT SULFURIC ACID.

	Corrosion Rate Expressed as Change in Weight, g. per g. ($\times 10^4$),[a] average for two specimens each
Pure lead	+0.16
Tellurium lead	+0.78
1 per cent antimonial lead	+0.53
Storage battery lead	−1.41

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[a] Due to the irregular shape of the specimens it was impossible to measure their area and hence their corrosion rates could not be expressed in the more customary units of "inches of penetration per year."

Stressless Corrosion Followed by Fatigue:

To determine whether stressless corrosion in the battery acid followed by fatigue in air might not damage the alloys as much as the simultaneous action of corrosion and fatigue, a series of fatigue specimens of each of the four alloys was corroded for one week at 77 F. in 38 per cent sulfuric acid. The acid was thoroughly agitated with air during the corrosion. The specimens were removed from the acid, washed with soap and water, dried, and the *S-N* curve determined on each series (Figs. 6 to 9). The results are shown in Table VI. All fractures, with the exception of the storage battery lead, were found to be intergranular at the surface. The storage battery lead broke sharply with a single crack perpendicular to the axis of the specimen. The specimens of the first three alloys that were tested at loads where appreciable plastic deformation occurred in the neighborhood of the fracture showed evidence of rupture of the sulfate film over the grain boundaries, although the film over the grains was undamaged (Fig. 22).

TABLE VI.—ENDURANCE LIMITS OF SOME LEAD ALLOYS TESTED IN AIR AT 1785 RPM. AFTER STRESSLESS CORROSION IN 38 PER CENT SULFURIC ACID.

Pure lead	475 psi.
Tellurium lead	1 300 psi. (?)[a]
1 per cent antimonial lead	1 200 psi.
Storage battery lead	2 050 psi.

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[a] Results on the tellurium lead are to be regarded with suspicion because only four specimens were available.

Notched-Bar Fatigue Tests:

As will be described later, the notch sensitivity of the pure lead was also determined at 1785 rpm. It was found that the fatigue limit of pure lead was only 170 psi. (Fig. 12) when the specimen had a reduced section formed by a 60-deg. V notch cut by a standard threading tool (Fig. 13) instead of the polished reduced section with a 2-in. radius as used on all other tests.

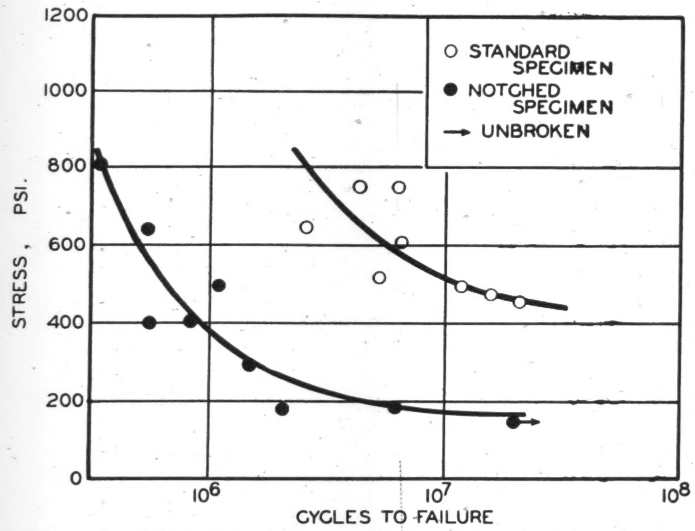

FIG. 12.—Effect of Notches on the Fatigue Strength of Pure Lead.

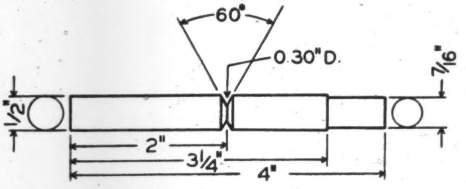

FIG. 13.—Notched Fatigue Specimen. The Radius at the Bottom of the Notch was Undetermined.

Commercial Tests:

It was originally planned to have a manufacturer of storage batteries give these same alloys the identical laboratory test given all prospective storage battery alloys under investigation in the manufacturer's laboratory. However, a survey of five leading battery manufacturers disclosed that all of them had given up laboratory testing of new alloys in favor of actual performance tests, using the alloys cast into battery grids. The reason for this has been complete lack of correlation between laboratory tests and performance tests either in car service or on a laboratory scale. The significance of this will be pointed out later.

DISCUSSION

Correlation of the Different Tests:

The corrosion resistance of lead to sulfuric acid is dependent upon the maintenance of the protective sulfate film. An examination of the changes in weight during the stressless corrosion test (Table V) shows that the first three alloys gained weight and the last alloy lost weight. Interpreted in terms of film formation, this means that the pure lead, tellurium lead, and 1 per cent antimonial lead built up protective films against the acid while the storage battery lead could not form a permanent film. The pure lead showed the smallest change in weight, the 1 per cent antimonial lead next, and the tellurium lead the most. Hence the pure lead probably had the thinnest protective film, which in a static corrosion test protected it amply against attack. In corrosion-fatigue this protective film offers so little resistance against the acid that it affords no protection, and in addition the fatigue strength of the lead is so poor that it is unable to carry any load under corrosion-fatigue. The tellurium lead combines a somewhat better fatigue strength with a much thicker protective sulfate film to give a corrosion-fatigue strength of 400 psi. The ratio between corrosion fatigue and fatigue limits is 0.76. The 1 per cent antimonial lead has the best combination of protective film and fatigue strength to give the highest ratio, 0.87. Considered on this basis, this alloy is least damaged by combined cyclic stress and corrosion in 38 per cent sulfuric acid. The storage battery lead, while unable to build up a permanent protective film against the acid still has a high enough fatigue limit and sufficient resistance to the acid to give a corrosion-fatigue to fatigue ratio about equal to that of the tellurium lead.

Considered from this standpoint, one is led to the conclusion that the corrosion-fatigue strength of these alloys is a balance between corrosion resistance and fatigue strength. Neither one determines it alone.

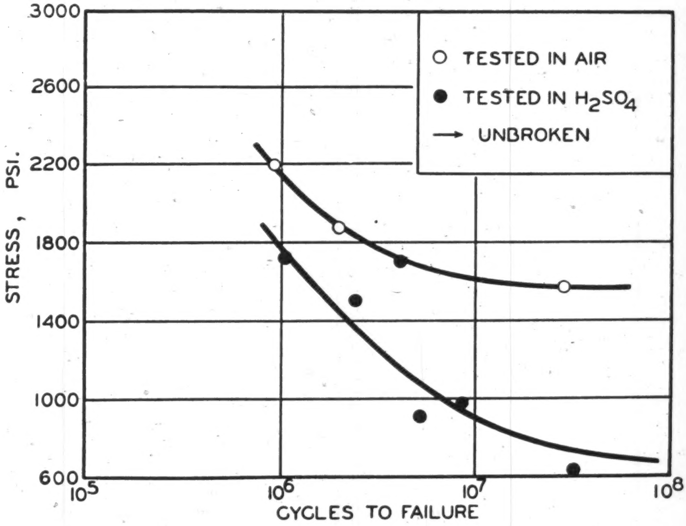

FIG. 14.—Fatigue Curves for Lead Containing 1.0 per cent Tin and 0.1 per cent Magnesium.

Variables in Fatigue Testing Applicable to this Work:

Many of the difficulties in comparison of the alloys arise because of their widely different physical, mechanical, and chemical properties. The tensile strengths of the alloys vary from less than 2000 psi. for the pure lead to 7600 psi. for the storage battery lead (**29**), while even such a property as recrystallization time at room temperature following cold working varies from 25 to 35 sec. for the pure lead to probably days for the tellurium lead (**5**), short recrystallization times for these alloys usually being associated with a tendency for coarse grain size and *vice versa*.

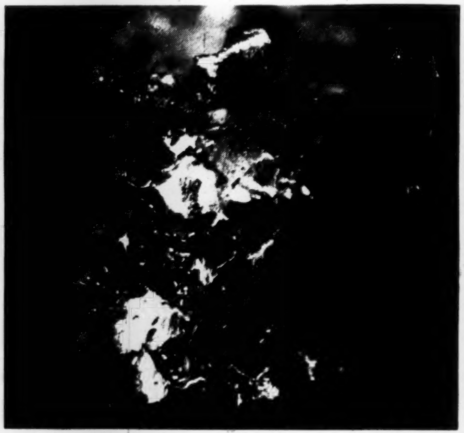

FIG. 15.—Intergranular Surface Cracks in the Region of the Corrosion-Fatigue Failure of Pure Lead. Etched with Ammonium Molybdate (× 11). (Reduced to 0.8 size in reproduction.)

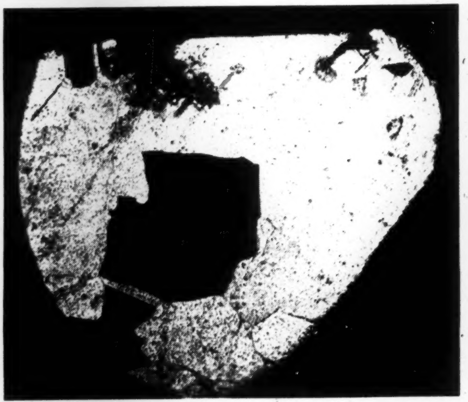

FIG. 16.—Corrosion-Fatigue Cracks (Intergranular) on the Surface of Pure Lead in the Region of the Failure (Right Edge): Etched with Villelas Reagent, 1 part HNO_3, 1 part Glacial Acetic Acid, 4 parts Glycerine (× 11). (Reduced to 0.8 size in reproduction.)

For strictly comparable results the grain size of all specimens should have been the same although it is generally held that grain size has little effect on fatigue strength (**4**). This was an obvious impossibility because of the interference of alloying elements on the development of an equilibrium grain size. The pure lead developed a relatively large grain size (Fig. 16), the 1 per cent antimonial lead an intermediate grain

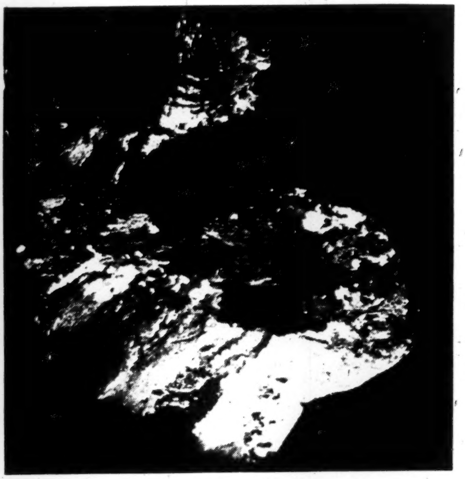

FIG. 17.—Cross Section of Fatigue Fracture in Tellurium Lead. Fracture Follows Old Grain Boundaries; Recrystallization is Incomplete. Etched with Ammonium Molybdate (× 11). (Reduced to 0.8 size in reproduction.)

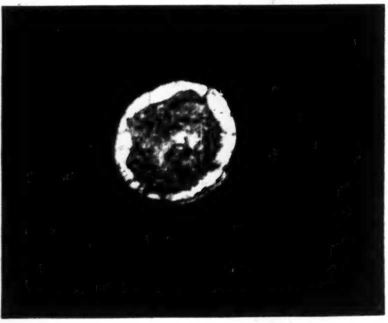

FIG. 18.—White Ring of $PbSO_4$ Around Outer Edge of Corrosion-Fatigue Fracture in Storage Battery Lead. Unetched, Vertical Illumination (× 2.5).

size, the tellurium lead a fine grain size (Fig. 17), while the storage battery lead can only be said to have had a fine structure (Fig. 19) because of the heterogeneity of its structure. It was desirable, but impossible, to determine the grain size on each specimen because of experimental difficulties. The pure lead showed a larger grain size in the region of fracture after testing. This is because of grain growth during the self-anneal immediately following the fracture and is caused by the stressing during the test and by plastic deformation occurring at the moment of fracture.

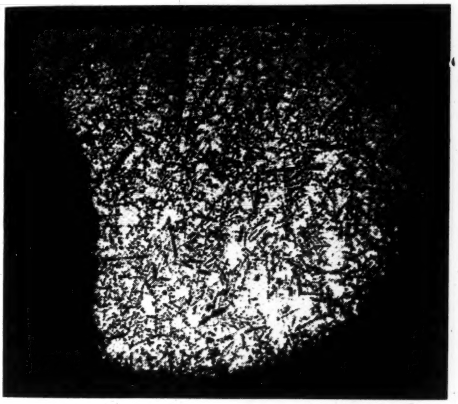

FIG. 19.—Transcrystalline Corrosion-Fatigue Surface Crack near the Failure (Left Edge) in Storage Battery Lead. Etched with Glacialacetic Acid + H_2O_2 (× 11). (Reduced to 0.8 size in reproduction.)

The effect of the aging treatment used probably raises the fatigue strength as shown by Beckinsale and Waterhouse (7) who found that, "... previous annealing in practically all cases retarded the failure by combined stress and corrosion." The aging treatment may either increase or decrease the time of recrystallization, according to Beck (6), depending upon the manner in which the aging treatment was performed. Overaging, as done here, lengthens recrystallization time considerably, may affect the endurance limit, and certainly does not reproduce commercial practice where the grids are aged at room temperature. In the pure lead the endurance limit seems to be the same for the various aging treatments although the initial portions of the endurance curves are different. This is not true for the storage battery lead. The difference probably arises from the fact that the mechanism of aging in the pure lead is a relatively simple process while in the storage battery alloy the aging must be a complex process due to the relatively large amounts of impurities and the fact that both ends of the lead-antimony system show decreasing solid solubility with temperature. Thus the final state of aggregation and hence the mechanical properties would depend upon the manner of aging.

The manner in which the fatigue specimens are worked influences their resistance to cyclic stress (see Table III). The hand forging used on these alloys lacks the uniformity of any type of mechanical working and undoubtedly results in a nonuniform recrystallization and grain size. Machining stresses or the relief of forging stresses during the machining may be of importance also. Alloy 9Sb, the storage battery lead, being unworkable, was tested in the cast form, further invalidating comparisons.

The treatment given these alloys is probably intermediate between a treatment that would give better results all around and a treatment designed to give the poorest possible results. Thus, coating the specimens with grease while determining the fatigue strength in air delays free access of air to the surface of the specimen and this, according to Haigh and Jones (16) is apt to raise the fatigue limit of lead although Gough and Sopwith (12) do not agree. But the coating of grease does keep the surface bright and free from atmospheric attack, particularly during the longer runs. Haigh and Jones also found that the effect of corrosion on the fatigue strength varied considerably with the manner in which the corroding agent was applied to the specimens. Total immersion in the corrodant seemed to keep the specimen cooler and hence it generally raised the fatigue strength although total immersion also prevents free access of air to the surface which is necessary for maximum corrosion. Application of the corrodant by wick action or in droplets presumably did not cool the specimen as much and hence did not give a fatigue strength much different from that obtained in air.

The effect of creep has been entirely neglected in this paper. As Moore and co-workers have shown (**18, 19**), creep is a very important factor in the fatigue testing of lead. To evaluate its effect, tests must be run at a number of different cycle frequencies. It is hoped to continue this work and run such a series of tests after the war.

The author also realizes that a cycle frequency of 1785 per minute does not necessarily reproduce the frequency of the cyclic stressing occurring in automative or other batteries during use.

Application to Grid Alloys for Batteries:

From the fact that 9 per cent antimonial lead is the most widely used alloy for acid storage cells, it is possible to deduce by inference from the above results and other sources[7] the properties that an alloy must have to be used successfully as a grid material in a storage battery. These properties are:

1. Castability. It must be possible to cast the alloy into the intricate grids in an automatic machine.
2. Pastability and formability, so that the active material may be pasted into the grids and the plates formed therefrom.
3. A fatigue limit in air of probably at least 1500 psi. with a corrosion-fatigue limit in battery acid at least 75 per cent of the limit in air.[8]
4. An adequate corrosion resistance so that the battery acid will not be contaminated by materials from the grids, thus causing short life or self-discharge.

The 1 per cent antimonial lead alloy whose ratio of fatigue limit in air to corrosion-fatigue limit in the battery acid is nearly unity is an interesting case. It is not a satisfactory alloy for automotive battery grids because it does not meet the first two requirements stated above but its fatigue and corrosion-fatigue properties, while somewhat lower than seems necessary, indicate that it should be a satisfactory grid alloy. Schaefer (**27**) cites unpublished tests to prove it gives very satisfactory performance as a grid alloy.

Similarly, Schaefer (**27**) cites tests on an alloy composed of 1 per cent tin, 0.1 per cent magnesium, balance lead, that showed outstanding properties as a grid alloy in laboratory cell tests but failed utterly in an automotive battery. Batteries with this alloy as the grids showed only 30 to 40 per cent of the life of standard batteries and failed by intergranular disintegration of the grids. The fatigue limit of this alloy in air (Fig. 14) was found to be 1550 psi., while its corrosion-fatigue limit in battery acid is only about 650 psi. This shows the need of an adequate corrosion-fatigue strength in battery alloys.

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[7] Chiefly private correspondence from various battery manufacturers.

[8] Using a cycle frequency of 1785 per minute as employed here. Lower cycle frequencies would probably reduce these values because of creep.

MECHANISM OF CORROSION-FATIGUE ACTION IN LEAD

Effect of Recrystallization:

Lead differs from all other common metals upon which much fatigue and corrosion-fatigue data are available in that when tested at room temperature it is above its recrystallization temperature. This means that the structure is unstable to the degree that the smallest possible applied load will cause plastic deformation if applied for a sufficiently long time. The creep of lead under its own weight and its inability to be work hardened more than instantaneously are the results of this. It also affects fatigue testing, making frequency of cycles of stress a major factor.

The structural instability caused by the low recrystallization temperature may influence corrosion-fatigue life considerably because of its effect on the stability and permanence of any protective films that may be formed on the lead during corrosion. The film of $PbSO_4$ when formed will form a uniform layer over the surface contiguous with the structure underneath. The film, being a chemical compound, will have quite different elastic and plastic properties from the lead itself. If the lead is then stressed in any manner the greatest concentration of stress will be at the grain boundaries which lie at the surface (as shown by the fact that polycrystalline materials buckle at the grain boundaries on the surface or perhaps very close to the surface, when loaded beyond the elastic limit). This stress concentration (it need not exceed the yield strength of the lead) will undoubtedly cause rupture of the brittle $PbSO_4$ film in the areas lying over the grain boundaries. The stressing which produced the discontinuities in the film would also produce a tendency towards recrystallization, grain growth, or in other words, grain boundary migration in the lead underneath. If recrystallization does not, or cannot, take place upon stressing, there nevertheless exists a potential force of recrystallization. This potential force undoubtedly exists during the cyclic stressing of lead. Specimens removed from the machine before failure has occurred and macroetched show recrystallization at the center of the reduced section. Since the recrystallization force is present and is concentrated at the grain boundaries, the discontinuity of the protective lead sulfate film at the grain boundaries is widened. Since the grain boundary material in any metal is the most active chemically and since this activity is probably increased by the recrystallization tendency, it is logical that the chemical attack on the lead by the sulfuric acid will proceed most rapidly at the grain boundaries since the sulfate film over the grain boundaries has already been extensively damaged by the cyclic stresses. Thus after a short period of cyclic stressing in the presence of sulfuric acid the grain boundaries at the surface of the lead will be corroded away, essentially producing a surface covered with fine notches. This is the initial stage. It is now necessary to see how the corrosion-fatigue crack is propagated.

Propagation of the Fatigue Crack:

The obvious method of crack propagation is by notch action, although it is customarily assumed that a soft material like lead which cannot be permanently work hardened at room temperature does not exhibit notch sensitivity. It was observed at an early stage in this work that specimens with circumferential tool marks or scratches failed by the formation of deep cracks at the root of each tool mark (Fig. 23). Thus it was decided to determine the endurance limit on a series of specimens which, instead of having the usual 2-in. radius for the reduced section, had a 60-deg. V notch at the center, the diameter at the root of the notch being 0.30 in., approximately the same diameter as the normal specimen. As shown in Fig. 12, it was found that pure lead had a decided notch sensitivity, its fatigue limit with the 60-deg. V notch being only 175 psi. as against 430 psi. for specimens with a 2-in. radius on the reduced section.

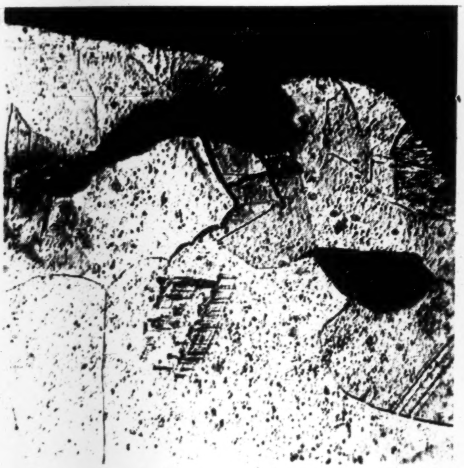

FIG. 20.—Intergranular Corrosion-Fatigue Cracks at Surface near Fracture (Right Edge) in Pure Lead Etched with Villela's Reagent. (× 50). (Reduced to 0.8 size in reproduction.)

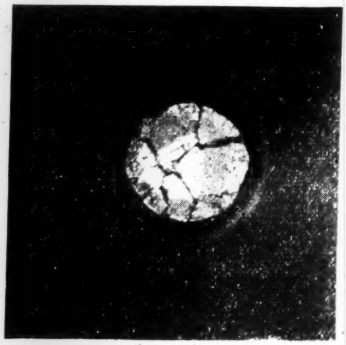

FIG. 21.—Ring Around Outer Edge of Fatigue Fracture in Tellurium Lead Showing Where Intergranular Fracture Changes to Transcrystalline. Unetched, Vertical Illumination (× 2.5).

In view of this pronounced notch sensitivity of lead, it is believed that the major portion of the propagation of the corrosion-fatigue cracks takes place by notch action, although other factors as described below contribute to the damage done by cyclic stresses when combined with corrosion.

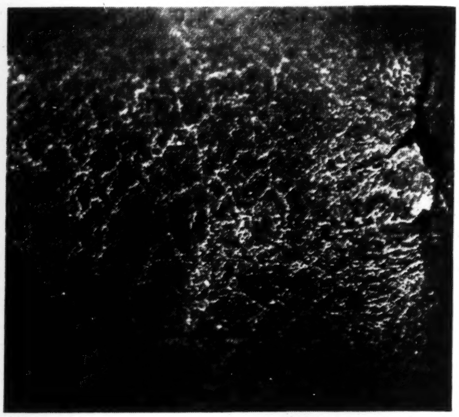

FIG. 22.—Ruptures in $PbSO_4$ Film on Pure Lead in the Region of the Fatigue Crack. Specimen was Corroded (Stressless) in 38 per cent H_2SO_4 Before Fatigue Testing (× 20). (Reduced to 0.8 size in reproduction.)

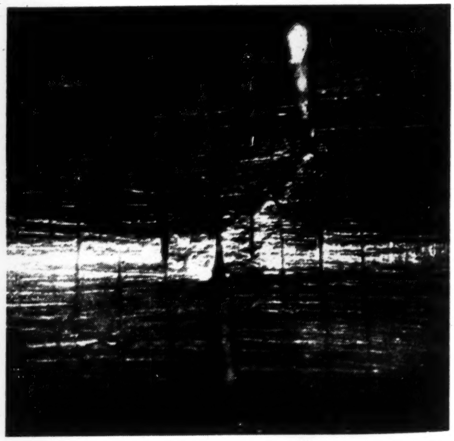

FIG. 23.—Fatigue Cracks Formed in Circumferential Tool Marks in Poorly Polished Pure Lead Fatigue Specimen (× 20). (Reduced to 0.8 size in reproduction.)

The fissures in the sulfate film and the intergranular cracks at the surface of the lead are opened during the tensile pulse and closed during the compressive pulse as the specimen rotates. This opening and closing of the fissures with the attendant sucking in and subsequent expulsion of the surrounding liquid is known as "breathing action." This breathing action undoubtedly also contributes to the propagation of the crack because the scouring action of the liquid in motion in the crack prevents the attainment of any chemical equilibrium in the crack. The breathing action may also suck off or break off minute pieces of the protective film and even particles of the metal itself, further damaging the lead. These particles of $PbSO_4$ and lead would, of course, exert a wedging action on the bottom of the crack if they were trapped in the crack during the compressive pulse.

There is probably another action occurring during breathing which contributes to the damage and hence to the propagation of the crack. This breathing action occurs with considerable rapidity, since it takes only about 0.017 sec. to go from the maximum stress in tension to the maximum stress in compression. Since the cracks open and close with such rapidity there must be considerable flash evaporation of water from the acid at the mouth of the crack as well as flash removal of dissolved permanent gases, principally hydrogen and oxygen. As the crack closes, some of these gases will be expelled but some may be trapped during the compressive pulse. Water vapor might be condensed in the crack by the pressure and exert wedging action while the permanent gases might be forced into solid solution in the grain boundary metal or the substructure unit boundaries adjacent to it, embrittling the lead and making it more susceptible to notch action. That such dissolved gases can seriously affect lead is shown by the effect of electrolytic polishing on the fatigue strength of the tellurium lead mentioned previously. When polished electrolytically, the tellurium lead, whose normal fatigue limit in air was 600 psi., failed under 553 psi. load after only 130,000 stress reversals. A similar effect has been described by Chaston (8). Although not investigated further the failure was probably due to solution of gas in the metal during electrolysis with subsequent embrittlement. This hypothesis is supported by the fact that two of these electrolytically polished specimens were tested 1 yr. after polishing when they were found to behave normally and lie on the endurance curve.

A somewhat similar explanation of corrosion-fatigue action has been advanced by Desch in the discussion of Gough and Sopwith's paper (12). He suggests that "... oxygen or other chemically active agents" admitted during the tensile pulse are highly activated when compressed with resultant damage being of a chemical nature. Vernon in the discussion of their next paper (13) disagrees and believes the damage results from the exposure of fresh, partially oxidized surfaces.

The corrosion-fatigue cracks are propagated by the mechanisms described above until they have progressed far enough to reduce the cross-section of the specimen to such an extent that the specimen deflects sufficiently under the load to shut off the machine. It is of interest to note that the corrosion-fatigue failures of the lead, tellurium lead, and 1 per cent antimonial lead (all plastic materials) in sulfuric acid are characterized by fine intergranular cracks covering the surface of the specimen near the point of failure (Figs. 15 and 16). The failures never consisted of the single circumferential fracture that occurs in straight fatigue failure. Alloys like the storage battery lead could hardly be expected to develop an "intergranular" fracture because of their heterogenous structure. In addition, the storage battery lead is probably brittle enough so that once the fatigue crack starts at the surface it will be propagated in transcrystalline manner (Fig. 19) by notch action alone.

Corrosion-fatigue specimens of the various alloys examined some months after testing exhibited a white ring around the outside edge of the fractured surface (Fig. 18). Examination of this ring showed it to be $PbSO_4$ formed from the H_2SO_4 which had slowly oozed out of the surface cracks into which it had penetrated during the test. The specimens had been thoroughly scrubbed with soap and water before storing.

Character of the Corrosion-Fatigue Cracks:

Corrosion-fatigue cracks propagated as outlined above should be fairly wide at the surface due to the scouring action during "breathing" and should taper down to fine cracks (intergranular in the plastic alloys) a short distance below the surface. Figure 20 shows that the cracks behave in this manner. As the crack progresses inward approaching the neutral axis of the specimen the force acting upon it during the tensile and compressive pulses is decreased; nor will the crack open as wide here as it does at its mouth. This should result in a decreasing tendency for the crack to follow the grain boundary. Thus at some point below the surface the crack will become transcrystalline rather than intergranular. The intergranular portion of the fracture will appear different than does the transcrystalline portion and hence a ring around the outside of the specimen marking the region of intergranular fracture will be visible. This ring is quite apparent on many of the fractured surfaces (Fig. 21). A similar ring has also been reported by Haigh and Jones (16) on lead specimens fractured in air. None of the straight fatigue fractures examined in this work showed such a ring.

CONCLUSIONS

From the preceding work the following conclusions seem justifiable:

1. It is necessary to over-age lead and its alloys in order to get reproducible results in fatigue testing as shown in Figs. 4 and 5. Lack of consistent aging is probably the cause of much of the discrepancy in the reported fatigue results on lead and its alloys summarized in Table III. This over-aging does not reproduce commercial battery grid practice, however.

2. The results obtained for the fatigue strength of pure lead are fairly consistent with the values reported by other investigators. The results obtained for the 1 per cent antimonial lead and the tellurium lead do not agree with previously reported values although this may be due to aging effects or the effect of creep and consequent variation of endurance limit with frequency of cycles of stress.

3. The corrosion-fatigue strengths of the four alloys in 38 per cent sulfuric acid are determined by a running balance between corrosion resistance and fatigue strength.

4. There is no correlation between fatigue strength in air, corrosion-fatigue strength in 38 per cent sulfuric acid, and stressless corrosion resistance as determined by loss of weight in 38 per cent sulfuric acid. There is a good correlation between fatigue strength in air and fatigue strength following stressless corrosion in 38 per cent sulfuric acid; which indicates that corrosion and cyclic stress occurring simultaneously cause serious damage.

5. Since the effect of corrosion-fatigue is variable in these four alloys, it is

logical to assume that it affects other lead alloys in similar variable fashion. Hence corrosion-fatigue is probably one of the variables that prevent correlation of laboratory and service tests on battery cells when the performance characteristics of new grid alloys are being investigated. In at least one case, the 1 per cent tin, 0.1 per cent magnesium alloy, a lack of adequate corrosion-fatigue strength was probably the chief cause of lack of correlation between laboratory and service tests in batteries with this alloy in the grids.

6. A mechanism for corrosion-fatigue action of sulfuric acid on lead is proposed. It is proposed that the $PbSO_4$ film which normally protects lead against sulfuric acid is damaged in two ways by cyclic stress: (*a*) Its adherence is affected by the tendency of the lead to recrystallize during stressing; (*b*) The cyclic stresses open up cracks in the protective film.

7. The pure lead tested was very susceptible to the notch effect, hence this is believed to be the chief factor in propagation of the fatigue crack. Breathing action due to stress reversal also may aid in propagating the crack.

8. The intergranular character of the corrosion-fatigue crack at the surface in lead is explained as is the marginal zone on the fracture.

Acknowledgment:

The author wishes to thank John L. Bray, Head, School of Metallurgical Engineering, Purdue University, for his counsel in this problem. Also, D. J. McAdam of the National Bureau of Standards for his kind suggestions and encouragement with the paper.

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PRACTICAL ELECTRIC RESISTANCE STRAIN GAGE PROCEDURES FOR STRUCTURAL TESTS ON SHIPS*

By W. V. Bassett[1]

Synopsis

Adoption of the electric resistance strain gage for studies of welding stresses in structures has required development of techniques for obtaining consistent results under outdoor and workshop conditions. Gage stability is necessary over longer periods than in other applications. Strain gage procedures are described in this paper which have given results accurate within ±500 psi. in many cases, even under the arduous conditions encountered when making strain measurements on welded ships under construction.

The two fundamental test methods are (1) to observe changes in strains due to operations producing stress in the structure, and (2) to measure relaxation of plugs trepanned or cut out from the structure after the operations are complete. The trepanning method has several advantages in shipboard work.

For the accuracy required in structural tests, the resistance strain gage and associated equipment are entirely satisfactory with respect to calibration and response. The cement bond between gage and metal can follow even plastic strains. Sources of error in structural welding tests are local strain effects, creep in the cement, insulation leakage, poor electrical connections, and temperature effects. These errors are minimized by suitable gage distribution, cementing and waterproofing techniques, rugged wiring and connections, and correct temperature compensation. On outdoor work it is preferable to make strain readings at night when temperatures are more stable.

Wiring problems have been eliminated on several projects by devising a mercury pool connector for making contact directly with the gages. Several other devices and procedures have been developed to improve reliability of strain gage readings and calculations.

In the investigation with which the author is associated, resistance strain gages have been applied to studies of welding stresses on subassemblies, ships under construction and completed ships; as well as structural models. Launching stresses have also been measured.

The versatility and convenience of the electric resistance strain gage recommend it for many applications. In the form now most widely used it is also known as the bonded wire strain gage and depends for its functioning upon the fact that the resistance of a metal wire changes with the strain to which it is subjected. The gage is composed of a length of approximately 0.001-in. diameter alloy wire bonded to

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thin paper in a pattern to provide a total length subjected to strain equal to several times the gage length. When the gage has been cemented to a structural member, the wire grid is rigidly constrained to undergo the same relative elongation, either tension or compression, as the material to which it is attached. The rather small resistance changes due to strain can be conveniently and accurately measured by as uitable adaptation of the Wheatstone bridge circuit.

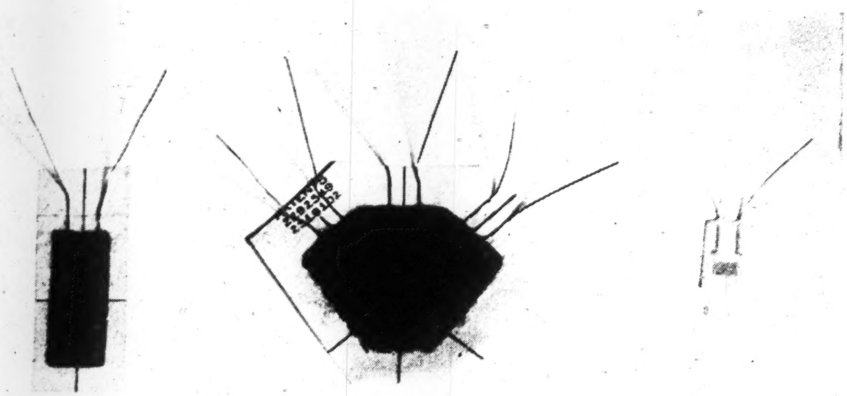
(*a*) Single element, 13/16 in. gage length.
(*b*) Three element rosette; gages at 0, 45, and 90 deg.
(*c*) Single element, 1/8-in. gage length. (For special applications.)

FIG. 1.—Typical Resistance Strain Gages.

Figure 1 shows three gage types. The wire grid is generally covered with felt, as the illustration indicates, for protection and thermal insulation. The wires seen projecting from the felt are heavier leads attached to the grid of fine wire for making electrical connections.

Bonded wire strain gages were first introduced in 1939. Their almost negligible weight and ability to follow extremely rapid strain variations made obvious their applicability to dynamic tests ranging from aircraft flight testing (**1**)[2] to the shock loads due to impact (**2**, **3**, **4**). As further development improved stability of the gages, a much more adequate stress analysis of aircraft fuselages and other structures through static testing was possible (**5**). In all of these cases the time of loading was too short for appreciable drift of the gage to occur, or drift could be checked by returning to the initial condition.

The convenience of attachment and low unit cost of the wire strain gage made it a logical choice for the several welding stress investigations (**6**) initiated, in part, by the structural failures of some Liberty ships. Since in this work loading conditions generally cannot be repeated, the gages are required to remain stable over extended periods, usually under the difficult conditions of extremes in weather, interference from building and outfitting work, and tight production schedules encountered in the shipyard. The success of such projects depends upon recognition of the factors influencing functioning and stability of the gages and the adoption of suitable techniques. It is the purpose of this paper to describe procedures found to give good results in various phases of an investigation of stresses, primarily those due to welding, in the structural members of a ship's hull. The investigation is being carried out by the Development and Research Branch of the Bethlehem Steel Co., Shipbuilding Division, using ships at several Bethlehem yards as subjects for experimental work.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 666.

Precautions necessary for obtaining reliable results may be considered in the following groups:

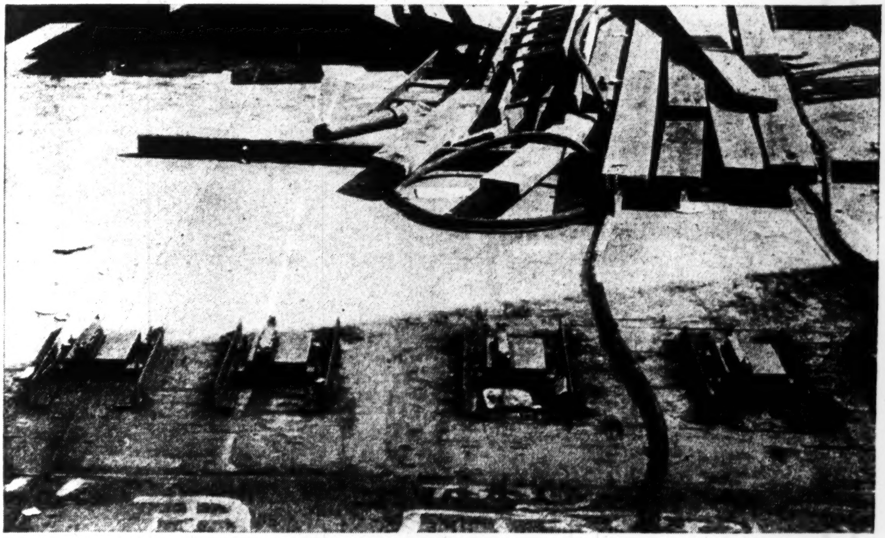

FIG. 2.—Working Conditions on Shipboard.

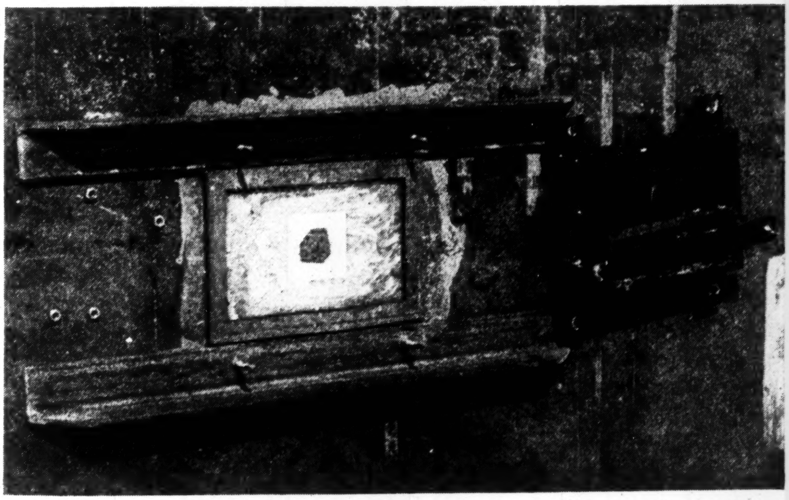

FIG. 3.—Location Adjacent to Butt Prepared for Welding, Showing Strain Gage, Protective Cover, and Watertight Gasket.

1. *Location.*—Arrangement of gages to avoid local strain effects, bending due to buckles, for example, which can influence or obscure the effects being measured.

2. *Attachment.*—Adequate bond between gage and metal, requiring cleaning and smoothing of metal surface, choice of a suitable cement, and the allowance of sufficient drying time to prevent creep of the cement.

3. *Functioning.*—(*a*) Elimination of electrical leakage by waterproofing gages and use of high-grade insulation.

(*b*) Dependable electrical connections.

(*c*) Control of temperature effects in the strain gages, electrical equipment, and the structure under investigation.

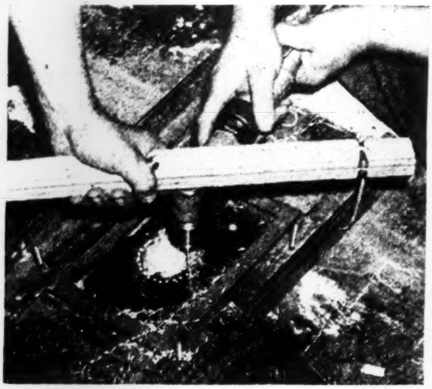

FIG. 4.—Trepanning Gage by Drilling.

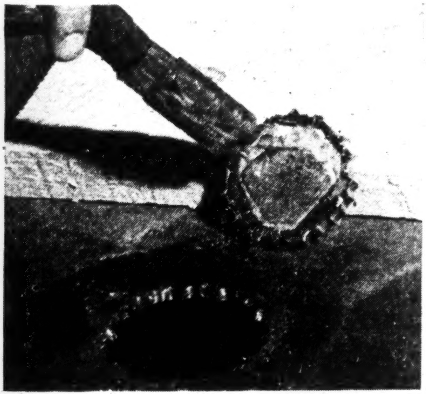

FIG. 5.—Making Strain Readings on Trepanned Plug.

TEST METHODS

The two fundamental test methods are (*a*) the normal procedure of reading gages before and after operations which apply load to the structure and (*b*) the trepanning procedure in which strain gages are used to measure relaxation of the plugs of metal to which they are attached as the plugs are trepanned or cut from the structure. The normal procedure gives the change in stress resulting only from the one or more operations occurring in the period between readings, while the trepanning procedure gives the total effect of residual stresses within the structure and stresses applied to the structure. Trepanning is usually carried out by drilling a circle of slightly overlapping holes around the plug, as shown in Figs. 4 and 5. Since the major components of residual or locked-up stress in ships result from a few subassembly and final assembly operations, generally similar results are available by either method.

The normal procedure has the advantages of giving results not directly affected by stresses due to rolling or other previous history of the material and of permitting the use of one gage installation for observations during several operations. The investigation can be carried on without any drilling or other permanent defacement of the structure. There are two principal disadvantages of the normal procedure. The first is that gage stability must be relied upon for the periods of several days to several months which may be required to carry out the operations under consideration. The second disadvantage is due to the fact that the cellulose cement type gages generally most suitable for field work have been found subject to an initial shift in strain indication when exposed to a temperature over 140 F. While the gages are not actually damaged until a somewhat higher temperature is reached, inconsistent readings may result. Consequently gages located less than about 9 in. from welding have not been considered dependable. According to one investigator, gages are more stable at relatively high temperatures if carried through an initial cycle to a temperature higher than that to be encountered in service before starting to take readings.

The trepanning procedure is performed after welding and other operations have been completed and requires one or two days, or, if special procedures are followed, only a few hours. The gages are exposed to accidental damage only during the time required for cementing gages and drilling out the plugs, and are required to remain stable only between the readings before drilling and after drilling. For these reasons the trepanning method is usually more satisfactory for shipboard work despite the disadvantages that holes left by the plugs must be repaired and the necessary crew and equipment are more extensive than required for the normal procedure. Stresses in and adjacent to welds can be determined by the trepanning procedure. In such regions of steep stress gradients the result must be recognized as an average value over the area of the trepanned plug.

STRAIN GAGE DESIGNS

Bonded wire strain gages are available as single-element gages with gage lengths ranging from $\frac{1}{8}$ in. to 6 in. for use when the strain component in a given direction is desired, and in a variety of "rosette" patterns for determining direction and magnitude of principal strains where the orientation of strain distribution is unknown. When working with ships the fore-and-aft and transverse strain components are frequently of as much interest as the principal strains. In the case of welds, strains longitudinal with and transverse to the welds are required. In both cases the "fan" pattern rosette (gages at 0, 45, and 90 deg.) can be aligned to give right-angle components directly. The "delta" rosette is less convenient for these purposes in that right-angle components are not directly apparent from inspection of the gage readings.

The rosette types just mentioned give the three strain measurements required to define analytically the principal stresses at a point 7).) Four-element rosettes provide an additional reading which can be used to check accuracy of the other readings. The check is particularly simple with the type of rosette composed of two gage elements at right angles, the remaining two elements, also perpendicular to one another, being located 45 deg. from the first pair. The algebraic sum of strain indications by one pair of gages at right angles should equal that of the other pair.

The gage wire grid has a projected width which, while small compared with the total length, will nevertheless vary resistance slightly in proportion with strain components transverse to the gage axis.

Baumberger and Hines (**8**) state that the maximum error due to neglecting the "lateral strain effect" is about ±3 per cent, and provides a complete development of formulas for taking the effect into account.

STRAIN GAGE INSTALLATION

Location:

In a plate or member assumed to have uniform stress over a cross-section, the actual strain is likely to be far from uniform. Local bending strains due to buckled plate or loads not quite centrally applied and unsymmetrical welding shrinkage effects can alter or obscure the direct strain measurement generally desired. The indication of a gage on only one surface of a plate has been found, for these reasons, to be 10 per cent in error as a measure of direct strain in the case of a plate which was apparently straight, and 35 per cent in error where a certain degree of buckling was apparent.

For plates, the practice of locating gages on both sides and using the average strain indication from each pair of opposite gages as a measure of direct strain minimizes error due to bending. Severely buckled plates should be avoided in any case as they cannot be expected to develop the same direct stress as straight plate for a given applied strain. Measurement of direct load carried by a structural shape requires selection of several gage locations at the cross-section in question to determine stress distribution and the average direct stress.

Cementing:

In securing an adequate bond between gage and metal, the first step is complete removal of paint, rust, and scale, leaving a smooth bright metal surface free from noticeable scratches, Fig. 6. A flexible-disk power grinder is very satisfactory for this purpose. The next step is to clean the area to remove every vestige of oil and grease, preferably just before cementing gages. The surface is swabbed with absorbent cotton soaked with acetone, then immediately rubbed dry with clean cotton. This process is repeated until the dry cotton shows no trace of discoloration.

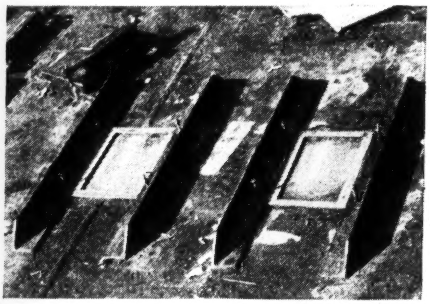

FIG. 6.—Gage Locations Ground and Smoothed, Including Location on Weld.

A number of cements are suitable, most of them composed of celluloid dissolved in a volatile solvent. While all may be equally satisfactory when thoroughly dry, the drying time varies considerably. For the older style gage made on relatively heavy paper, several commercially available cements are widely used. A 24-hr. drying period is recommended by one gage manufacturer, during the first half hour of which mechanical pressure is necessary. New style "quick-drying" gages are now available. When used with cement prepared by the manufacturer, they require only finger pressure for about half a minute when attached, and the recommended drying time is 6 to 8 hr. On account of the convenience of attachment, the "quick-drying" gages are being considered for general use even where the rapid drying feature is not important.

If reasonable care is used in attaching gages, there is usually no question of the reliability and constancy of the "gage factor" relating gage indication with actual strain, even for strains well into the plastic range. The real goal of cementing technique is to obtain a bond sufficiently free from creep over the time interval involved in the test, with a reasonable drying time under the prevailing atmospheric conditions. The recommended drying times mentioned in the preceding paragraph presumably refer to ordinary surroundings at room temperature and should be extended in case of cold or dampness, or artificial heating should be used. In outdoor work on shipboard the practice of preheating the location before gage installation and applying heat again for a period before waterproofing the gage has been adopted for all but ideal warm-weather conditions. Heating elements built into protective covers and portable 200-w. lamps with reflector bowls are proving very convenient for this purpose. While many tests of cementing methods have undoubtedly been made under various drying conditions, most of the results have not been compiled and made generally available.

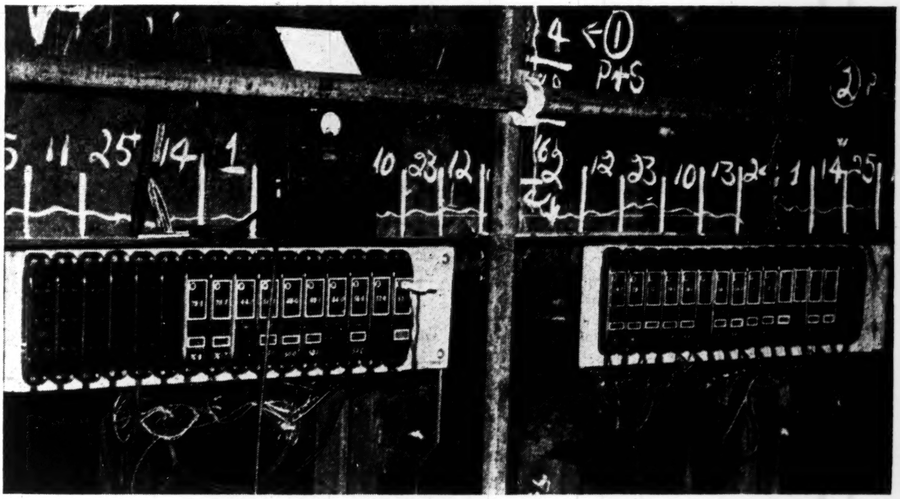

FIG. 7.—Central Plug Board Panel and Strain Indicating Instrument.

Waterproofing:

The need for waterproofing gages is readily apparent when it is realized that a leakage path of 1 megohm resistance between the terminals of the usual strain gage of 120 ohms resistance will have the same effect on strain indication as a stress of about 1800 psi. The paper on which the gage is made can absorb enough moisture from a reasonably humid atmosphere to provide an appreciable parallel path. In practice gages are coated with melted wax, preferably petrosene or ceresin, applied with a brush as soon as the proper cement drying time has elapsed.

While a change in parallel leakage

resistance between gage terminals cannot be distinguished from a change in strain, the resistance between the gage grid and the plate to which it is attached, and between the elements of a rosette, provides a satisfactory measure of the magnitude of possible errors. A portable battery-operated megohmmeter which applies a maximum test voltage of 25 v., sufficiently low to avoid damage to the gage, has been of definite aid in judging whether moisture can have affected a series of readings. It has also been found desirable to check wiring connecting strain gages to instruments.

Gages located on shipboard require protection from physical injury and the weather in addition to waterproofing. Figures 3 and 11 show two types of protective enclosure which have proved successful.

STRAIN INDICATING EQUIPMENT

The self-contained portable strain indicator, Fig. 7, developed especially for use with the resistance gage, has a slidewire Wheatstone bridge circuit supplied with 1000 cycle alternating current from a battery-operated oscillator. The bridge unbalance is amplified in a vacuum tube amplifier and indicated on a milliammeter. Use of alternating current has the advantage of cancelling out thermo-electric effects in the gage circuit. The fundamental characteristic of any bridge circuit is its sensitivity in detecting the change in an electrical resistance relative to the approximately equal resistance, in this case, against which it is balanced. The fact that relative change between the two resistances determines bridge balance is used to provide compensation for the effect of temperature on the gage and the metal to which it is attached.

Effects of Temperature Change:

The indicated resistance of an installed strain gage varies with temperature as well as with strain and absorbed moisture, as previously noted. The variation with temperature is a combination of the coefficient of resistance for the gage wire, generally relatively low for gages to be used in static tests, and the coefficients of expansion of the wire and the material being tested. The circuit can be made self-compensating for temperature by using as the "dummy" resistance, against which the strain gage resistance is balanced, another gage from the same manufacturer's lot as the strain gage. The dummy or compensating gage is attached to an unstressed piece of the material used in the structure under test. A temperature change unaccompanied by change in the stress pattern will affect the strain and compensating gages equally, with no resultant effect on instrument indication.

Correct temperature compensation requires that strain and compensating gages be at the same temperature, or at least that constant temperature differential be maintained. For this reason, several dummy plates carrying the compensating gages are distributed over the strain gage layout. Each dummy plate is located so as to follow the same temperature variations as the group of gages which will be connected with it for readings. The closest possible thermal contact between dummy plates and the metal of the structure is required. Appreciable differences between temperature of the structure and that of the atmosphere, or sudden temperature changes, make it necessary to provide insulation and shelter over the dummy plates. Since sunlight and shadows result in rapid temperature fluctuation during the day, with consequent rapid changes in stress pattern as well as compensation difficulties, it has become the practice in work on outdoor structures to make all strain gage readings at night after temperatures have stabilized.

A lesser temperature effect is due to the coefficient of resistance of the wiring. For accurate work where appreciable temperature change could be expected, strain gage and dummy leads have been made equal in length and of the same kind of wire. The use of fairly heavy copper wire, no smaller than No. 18, reduces the total resistance and, therefore, errors from this source.

The remaining effect of temperature change, that on the "zero" of the strain indicator, can be appreciable when the instrument is brought from a warm room to outdoor conditions. The zero has been taken as the instrument balance point which would result if dummy and strain gage resistances were exactly equal. Since the two resistances in general are not exactly equal, the balance point will be above or below the zero point. If now the gages are interchanged between the strain gage and dummy gage positions, the difference from the zero will be in the opposite direction. The average of these two instrument readings will be the zero point.

Electrical Wiring and Connection Resistance:

In using the resistance strain gage for structural stress analysis, one of the important problems is that of connecting a large number of gages, one after another, into the bridge circuit for taking readings. In cases where each gage is to be read more than ten or fifteen times, all gages may be wired to one or more central instrument locations. Simple wiring arrangements using well-insulated heavy copper wire, preferably solid conductor, with a minimum of changeable connections are desirable. Schemes using a common return have not been used in field work because, despite considerable care in gage installation and protection, one or two grounds are frequently found in each gage layout. Locating the grounds would require cutting the wiring assembly into small sections for checking, then reassembling.

The connection problem is complicated by the fact that variations in the resistance of changeable contacts between readings directly affect accuracy of the data. For example, a change in contact resistance of 0.016 ohm in the circuit of an ordinary 120-ohm gage has an effect on strain indication corresponding to a 2000-psi. stress change. Connections made with copper or brass binding posts and clean lugs have proved entirely satisfactory. Readings can be reproduced well within the accuracy of setting the strain indicator. Heavy brass plugs and jacks, Fig. 7, can be changed more rapidly and are equally satisfactory. Switches are generally undesirable for use in the bridge circuit. Even high-grade switches, while apparently reliable at first, give erratic results on account of wear and dirt after a period of use.

Portable Mercury Pool Connector:

A convenient solution to the problem, especially where relatively few readings of each gage are required, is to use a portable connector with a single pair of leads to make contact directly with the small connection wires on the gages themselves. The work involved in installing wiring and identifying terminals is thereby avoided. In trepanning work any attached wires are likely to be damaged in the drilling operation. The two obstacles to the use of a portable snap clip connector are contact resistance and the possibility of damage to the comparatively fine wires extending from the strain gages if subjected to several clamping operations.

The development of a mercury connector, shown in Figs. 5 and 8, consisting of a small plastic receptacle which contains two mercury pools has overcome these difficulties. When taking a reading, the ends of the gage wires, carefully cleaned of any wax or cement, are inserted through holes in rubber diaphragms into the mercury. An entirely satisfactory contact between the gage and the lead wires results. The diaphragms, even after several hundred readings, retain the mercury when the connector is held in any position or even shaken, yet no difficulty is encountered in making contact with one gage after another as rapidly as the indicator operator can observe and record the readings. Diaphragms are replaced when worn. The mercury connector has been used with success on several fabrication tests and in trepanning measurements on a number of ships. The only limitation to its use that has been found is weakening of the gage connection wires on account of amalgamation with the mercury. The wires can be expected to last for at least fifteen readings, which will cover all trepanning tests and most fabrication tests.

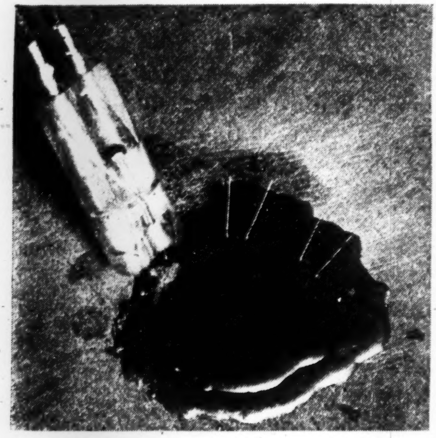

FIG. 8.—Waterproofed Gage and Mercury Connector.

NOTES ON PROCEDURE

Standardization:

When inconsistencies are found among a series of readings, the possibilities of erratic behavior of one of the dummy gages, instrument zero variation, and change in resistance within the portable leads and connector are likely to be brought up. It has been found desirable to keep track of these three items by following a regular "standardization" procedure during the course of a set of readings, though the effects are seldom of sufficient magnitude to justify their being taken into account as corrections. Dummy gages are periodically compared with an adjacent dummy or with a standard. Instrument zero and mercury connector standardization is facilitated by a zero check dummy. This device contains two gages selected, for convenience, to have nearly equal resistance. Four terminals are arranged to permit connecting the gages in both direct and interchanged positions. In addition, set screw terminals to accommodate a pair of discarded gage connection wires are provided leading to one of the gages, for use in testing the mercury connectors. The difference in indication between reading the gage through the connector leads and through the terminals is a measure of connector resistance.

Calculation:

The strain indicator gives readings of relative elongation in millionths of an inch (microinches) per inch which, for purposes of analysis, are generally converted to stress. Stress components from a pair of mutually perpendicular gages are easily computed using the modulus of elasticity and Poisson's ratio. The calculation of principal stresses from rosette readings is based on Mohr's circle. An article by Murray (**9**), followed by several informative discussions, fully describes Mohr's circle as adapted to rosette analysis. The solution can be carried out by several methods, among them the following: (1) graphical, (2) mathematical analysis using calculating machine, (3) geometrical computer, and (4) nomograph or alignment chart. The graphical method requires no particular setup and is satisfactory when doing a few calculations, but becomes tedious when many calculations are required. The considerable effort spent in resolving the algebraic and trigonometric expressions derived from Mohr's circle into a simple tabular form for calculating machine solution has proved worth while, for the machine method has become standard in this investigation. The geometrical computer, Fig. 9, is sufficiently accurate for checking and, since it is much faster and subject to mistakes of an entirely different nature, provides an excellent check method. The nomograph has been investigated and has been found to offer the same advantages as the geometrical computer.

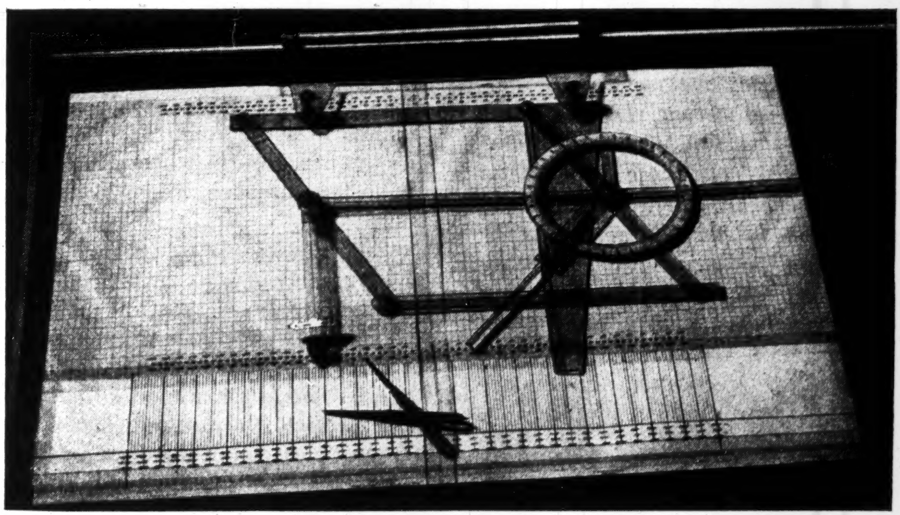

FIG. 9.—Geometrical Computer for Determining Principal Stresses from Rosette Readings.

APPLICATIONS AND RELIABILITY OF RESULTS

General:

Accuracy which may be expected from measurements with resistance strain gages depends upon the nature of the application. A change in stress as small as 100 psi. can be detected, and in a short-time reproducible test the combined effect on strain indication of all errors has been found to be less than $\pm 1\frac{1}{2}$ per cent. Possible limitations to accuracy for the test of short duration, as long as $\frac{1}{2}$ hr. under ordinary indoor conditions, are adequacy of the cement bond, consistence of gage response and calibration accuracy, reproducibility of connection resistance, instrument precision, and instrument reading error. In these respects the resistance strain gage technique may be considered beyond reproach for providing the degree of accuracy required in most structural strain measurements. Errors limiting the accuracy of structural tests, primarily gage creep and the influence of temperature change, are functions of time rather than of the strain being measured and are consequently more properly expressed as a margin than as a percentage.

Gage creep is apparent as a drift in the strain indication when there has been no corresponding change in loading. The direction of drift is frequently opposite to that of the strain which has been applied to the gage, which would indicate that the gage is seeking to return to its original condition. However, in other cases the gage drifts in the direction of the applied strain. Whether this represents creep of the metal or drift from a source within the gage itself has not been determined in this investigation.

Temperature variation while gages are being read or a different temperature distribution at any reading from that at the initial reading results in more or less inconsistent data. While procedures can be adopted to tie in temperature observations with strain gage readings to correct for the irregular drift in indication due to compensation errors, alteration of the actual stress pattern cannot be easily taken into account. It may be noted that such tests on the compensation effect as have been made as part of the work described show the single element gages to be practically perfect in this respect, while small discrepancies may be found between elements of a rosette when used over a wide temperature range.

Residual Stress Pattern in Deck and Shell of Ships:

The first extensive application of electric resistance strain gages in the present investigation was for determination of the residual stress pattern in portions of the deck and shell of Liberty and Victory ships, using the trepanning procedure. Rosette gages were attached on both sides of the plate at each location. Initial readings were taken in the evening when temperature conditions had stabilized, after which the plugs were drilled out. Final readings were taken on the ship, sometimes with the plug still held in place by one ligament, as soon as the plug had returned to ambient temperature following trepanning.

An additional source of error present in this work was the possible detrimental effect of the trepanning

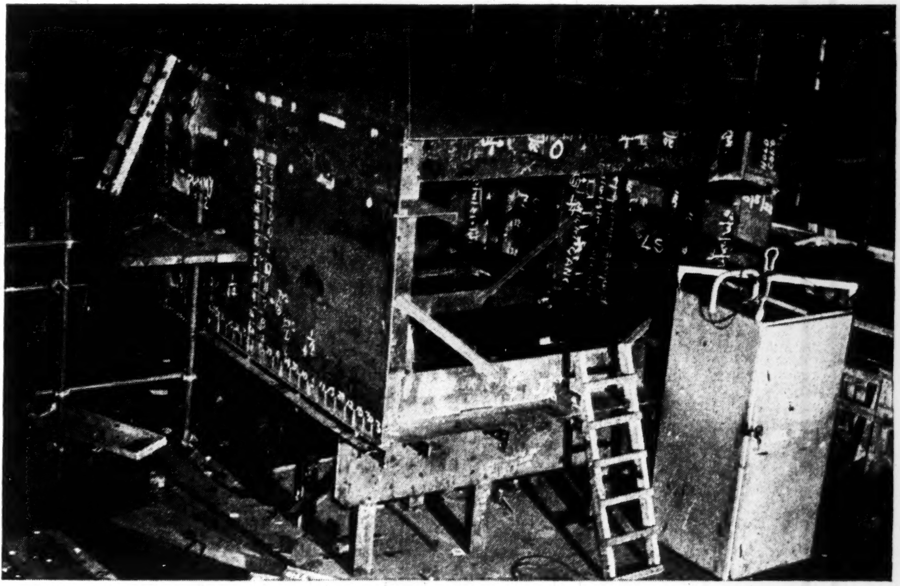

FIG. 10.—Structural Model for Study of Girth Weld Sequence.

operation on relaxation of the plug and performance of the gages. Studies made by other investigators have indicated that the trepanning procedure is sufficiently reliable for use in structural stress analysis. No direct check of accuracy was possible in the work described here, since any comparison involved inevitable differences between locations on the same or different ships. A composite plot of stress adjacent to a seam weld in deck plating, Fig. 12, based on measurements by trepanning at three different locations on one ship, shows a maximum spread of about 3000 psi.; most of the points being in better agreement.

The residual stress pattern in a completed ship is the summation of initial residual stresses in the plate such as those due to rolling, forming and flame cutting, welding stresses set up in subassembly operations, final assembly welding stresses, and the stress patterns due to hull loading condition and temperature distribution. Separate studies of all these components are being made.

Girth Welded Investigation with Structural Model:

The effect of the sequence followed in making a girth weld on residual stress distribution is being studied with a model, Fig. 10, representing the amidships portion of a Liberty or Victory ship to approximately one-fifth scale. Gage locations are distributed both forward and aft of the weld. When strain readings following one girth weld sequence have been completed, the model is cut apart, stress relieved, and reassembled by another girth weld sequence. Since strain gages of the ordinary type used on the model would be ruined by the stress-relieving temperature, new gages are used for each sequence.

Figure 13 shows part of a stress

pattern obtained from the model. It is believed that the results are accurate within a range of about 1000 psi., sufficient to give a picture of the pattern of stress as well as the approximate magnitude. Since initial and final readings were taken within three to five days of one another, gage creep was not serious. Although the model was located indoors with a view to avoiding temperature problems, the normal daily variation within the shop and drafts from frequently opened doorways gave some trouble.

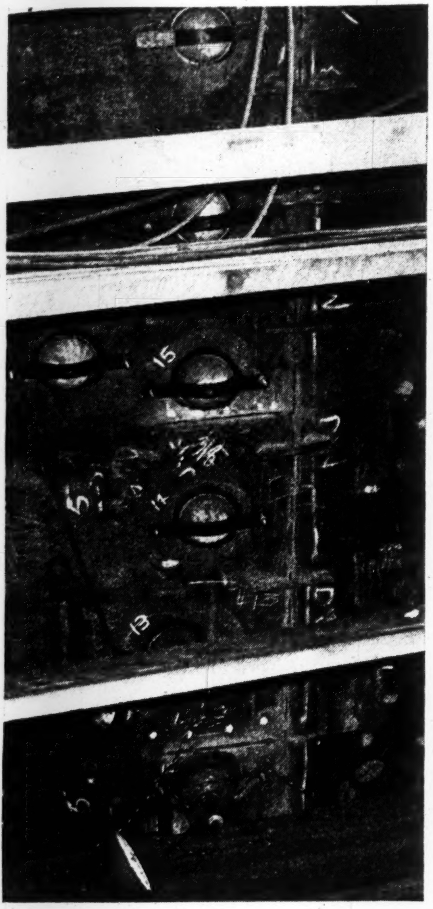

FIG. 11.—Shipboard Strain Gage Installation, Showing New Type Protective Cover.

Results obtained with the model have been decidedly encouraging. Radically different residual stress patterns, generally consistent with welding theory, have been obtained from each of the three welding sequences so far investigated, though the maximum stress values were approximately the same. A girth weld sequence on a full-size ship has been analyzed with strain gages with the intention of repeating the sequence on the model to provide information on the scale effect.

Long-Time Tests:

For strain measurements extending over a period of mothhs the bakelite type strain gage is probably better suited than the ordinary cellulose cement type gage, although some results have been obtained with the latter type during construction of a cruiser hull. Such tests should be run in conjunction with creep tests of gages attached under exactly the same atmospheric conditions.

Launching Stresses:

The "static" strain indicators have been used successfully to catch the peak stresses in the hull during launchings of several vessels ranging in size from landing barges to heavy cruisers. The magnitude and location of the highest stresses have been determined. These studies have been of interest for comparison with calculated stresses during launching, which provides an opportunity for a full-scale test of the hull structure under loads approaching working conditions. The program will be extended to include a continuous strain record throughout launching obtained by means of a multi-element oscillograph. Results obtained by the rather makeshift strain indicator method are believed correct to within about 10 per cent.

a reciprocating engine crankshaft without removing it from the bearings. Load was applied by jacking. Strain gages were attached 90 deg. apart around the circumference of the rod. This application emphasized the necessity for considering non-axial loading in locating gages, for despite every effort to line up the jack and weighing rod, when jack pressure was applied one or

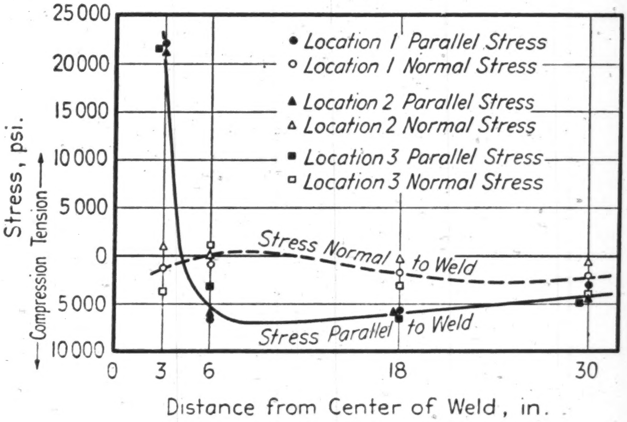

FIG. 12.—Typical Stress Pattern Adjacent to Weld in Deck Plating of a Ship, Obtained by the Trepanning Method.

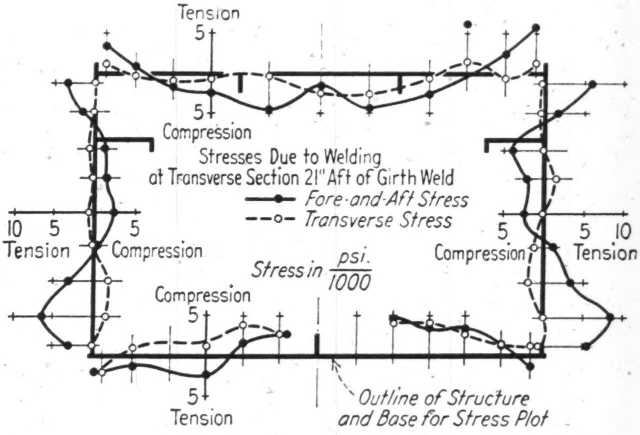

FIG. 13.—Typical Stress Pattern Obtained from Structural Model.

Weighing Rod:

A weighing rod 3 in. long was constructed of $1\frac{1}{8}$ in. diameter steel rod for use in studying the deflection of another of the gages at first showed tension. As the contact surfaces of the rod deformed to centralize the load, distribution of compressive stress became more uniform; although in no case could one of the gages alone be relied upon. The average of the four gage readings was used as a measure of load.

CONCLUSION

The electric resistance strain gage has been found a valuable tool for stress analysis on structures. Test methods and techniques are in use or can be devised to provide stress measurements of accuracy sufficient for practical purposes in almost all problems which may be encountered. Conditions imposed by work out of doors, on shipboard, or in the shop have required that the characteristics of the equipment be recognized and suitable precautions taken to eliminate or minimize the inherent errors.

Acknowledgment:

The author wishes to express his appreciation of the cooperation given by his associates in the Development and Research Branch of the Bethlehem Steel Co., Shipbuilding Division, in the preparation of this paper.

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DISCUSSION

Mr. J. Vasta[1] (*by letter*).—Lord Kelvin has been credited with saying that "the essential in studying any phenomenon is to make measurements." This is true in every engineering field; the ship structure is no exception. To study the reaction of a ship structure under a known applied load, it is essential to measure strains at chosen locations and compare these with theoretical values. In doing this, the electric resistance strain gage plays an important role. Because of its relatively small size and weight, it possesses a flexibility which cannot be obtained with mechanical gages. Moreover, its short base length plus its ability to send its report over a small pair of wires to a distant point makes it especially useful for measuring strains at otherwise inaccessible locations.

Credit for being the first to use the SR-4 electrical resistance gages for ship structure investigation probably belongs to the U. S. Maritime Commission. In the summer of 1941, a series of full-scale tests on a reinforced-concrete hull was conducted to obtain information on the basic assumptions that governed the structural design of such vessels. The many precautions that the author of the paper points out so lucidly were taken. However, field conditions, particularly the excessive moisture in the test tank where strains were sought, prevented the setting of the cement, hence the electrical gages could not be made to adhere to the reinforcing bars of the structural element under test. It is gratifying to note that these early difficulties have now been largely eliminated by a combination of improved technique and improved cementing materials. Incidentally, this test was carried forward by the use of mechanical strain gages.

Although these early trials gave a somewhat negative result, faith in the electric resistance gage was not dimmed. The Maritime Commission planned a comprehensive test on a steel vessel of the Liberty type wherein much of the experience of previous investigators was pooled to insure a successful test. The Liberty ship was tested during the summer of 1944 and required a period of approximately six weeks. Well over 11,000 electrical strain gage readings were taken during this period and a relatively small percentage of readings was lost. This speaks favorably for the technique and care exercised in preparing the strain gage stations and in protecting them against moisture and physical damage from the traffic of the testing personnel. The result of this field experimentation bears out the faith in the electrical gage as a reliable measuring instrument when applied to the structure with all the precautions that the author describes in his paper.

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The question of drift, or lack of gage stability, is one that will always cause some concern. The cause should be sought. Future technological developments of the bonding material used to attach the gage to the structure may eliminate this annoying deficiency. Public enemy No. 1, as far as the electrical gage is concerned, is the moisture present in the atmosphere surrounding the test specimen. Properly cemented gages on tests performed under ideal conditions in the laboratories show negligible drift for such periods of time as are usually considered ample for the completion of the experimental investigation. The situation in the field is usually entirely different and the success of the enterprise depends on the care exercised and technique employed in attaching and protecting the gages. In the Liberty ship test referred to above, all the gages were left on the structure for a period of approximately four weeks. Strains measured at the completion of the loading cycle did not, in the main, check absolutely the zero strains measured at the beginning of the test. If this lack of agreement between the two zero readings—taken at the initial and final stages of the tests—can be ascribed solely to the phenomenon of drift and to no other cause, then there is evidence that all except a few of the strain gages drifted. The average drift for the entire group was about 75 micro-inches, which corresponds roughly to 2000-psi. stress. Stresses induced by loading were of the order of 25,000 psi. The accuracy of the data, however, was much closer than the amount indicated by the drift, because, in many instances, while one gage element on the top face of the plate would show an apparent elongation, the opposite gage element on the other face of the plate would show some contraction, thereby tending to neutralize the effect mentioned. It is believed that this phenomenon of drift results from some minute plastic deformations that take place in the cement itself. It is hoped that future technical developments in this direction will eliminate such difficulties experienced in the field.

The state of stress at any one point on the structure can be computed from strains measured in three different directions. This requires that the electrical gage have a minimum of three elements. A strain gage station on a plate must consist of two such "rosettes," one on each face of the plate—a total of six wire elements. The strains measured on each pair of elements must be averaged to obtain the strain in their direction at the middle plane of the plate. Strains measured on only one face of the plate will involve large errors, certainly much larger than those the author describes in his paper. In some instances, on the structural tests of the Liberty ship, the difference between top and bottom strains on any one particular pair of elements was as much as 100 per cent, meaning, thereby, that the plating to which the gage was attached had an appreciable bending stress and a curvature which was not visible to the eye. The experience gained in testing about a dozen steel ships indicates definitely that strains measured on one face of the plate alone will lead to deceiving and inaccurate conclusions. Rational comparisons between measurements and theory are destroyed if the experimenter measures strains on only one face of the plate without some means of evaluating the strains resulting from changes in plate curvature.

When a large structure, such as a ship, is tested, it is almost impossible to eliminate the thermal effects resulting from changes in temperature. It is impossible to expect the "dummy" gage to do this because the restraint of the structure to temperature variations has been found to be different on all three axes of the gage elements. Therefore, even if it were possible to obtain an accurate record of the temperature changes in the plating to which the gage is attached, a preknowledge of the effect of restraint would be necessary in order to correct the strain for the temperature effect. An attempt at eliminating this difficulty consists of taking strain readings during the night, hoping that the air temperature surrounding the structure has stabilized itself and will be the same as during previous readings. It is impossible, of course, to control temperature fluctuations from night to night. However, these fluctuations will be of a small order, and their influence on the accuracy of the data not significant. Nevertheless, the precaution should be taken to select "dummy" gages and acting gages from the same box, and similarly, if possible, the indicating instruments ought to be kept within one room at a reasonably constant temperature.

The interest shown by the various shipbuilding organizations toward solving, by a systematic program of research, the many problems related to welding procedure and its effects, is a commendable one. It is only through such systematic approach that the experimental facts can be determined. In this endeavor, a knowledge of the limitations of the gage and its idiosyncrasies will go a long way toward lending weight to the experimental findings. The author of this paper is to be congratulated for bringing up to date the many pertinent points considered essential in the application of the electrical gage to structural investigations.

MR. W. V. BASSETT[2] (*author's closure by letter*).—Mr. Vasta's comments on some of the first applications of resistance strain gages to ship structures are appreciated. His emphasis on the necessity for control of moisture effects and gage instability or drift, and on the use of gages on both surfaces of a plate is decidedly worth while.

In connection with Mr. Vasta's statements on thermal stresses and restraint, a brief description of a test recently conducted by the Development and Research Branch of the Bethlehem Steel Co., Shipbuilding Division, may be of interest. Temperatures and changes in longitudinal strain over the amidships cross-section of a waterborne 320-ft. hull of relatively simple construction were followed for a 48-hr. period. Weather conditions were ideal for this test; on both days bright sunlight shone from a nearly cloudless sky, and nights were relatively cool. Temperatures of the structure varied through a 70 F. range. The strain readings obtained indicated a total range of stress variation of 8000 psi.

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[2] Engineer, Development and Research Branch, Central Technical Dept., Bethlehem Steel Co., Shipbuilding Division, Quincy, Mass.

One of the most pronounced effects was that observed in the east gunwale which, when warmed 43 F. by the morning sun, developed a 6000 psi. change of stress in the compressive direction over a 2-hr. period. This stress increment is about 70 per cent of that which would theoretically result from a 43 F. temperature change under complete restraint. Simultaneously a compressive stress component of 1500 psi. was observed in the opposite bilge, while small tensile stresses were indicated in the other two diagonally opposite corners of the hull.

As the day progressed, the pattern of stress variation followed the directions and comparative magnitudes which would be expected from the observed temperatures. Correlation of absolute stress magnitudes with temperature would be, as Mr. Vasta indicated, a complex problem. Restraint evidently depends upon a number of factors, including the proportion of material in a structure subject to a given thermal expansion and its location with respect to the neutral axis of bending.

Stress and temperature variations for the two days were generally similar. During the night, strain gage readings agreed with those obtained 24 hr. previously within about ±10 microinches per inch. Temperature and strain indications were relatively steady by 4 hr. after sunset, but continued to shift slowly until sunrise.

SINGLE-STRIP COMPRESSION TEST FOR SHEET MATERIALS

By Harry LaTour[1] and Don S. Wolford[1]

Synopsis

This paper presents a new jig for testing sheet materials in compression using a flat single-strip specimen. The jig prevents lateral buckling of the specimen by providing continuous support in the form of flat guides. Both ends of the specimen extend beyond the jig body an amount exceeding the total deformation during the test. Consideration is given to the length of these extensions so that compression properties can be obtained on materials having yield strengths of 180,000 psi. and even greater.

Single-strip specimens having thicknesses ranging from 0.035 to 0.100 in. and solid cylinders cut from a homogeneous bar of heat-treated S.A.E. 4330 steel were used as a means of evaluating the results obtained in the new jig.

Results of single-strip tests on steels having thicknesses between 0.010 and 0.050 in. and yield strengths ranging from 50,000 to 180,000 psi. are given for the new jig.

The above comparisons were based on measurements of strain using Huggenberger tensometers. An adaptation of the Templin-Peters recorder system has also been applied to this jig for obtaining autographic load-deformation curves.

Tests made by the authors show that compression stress-strain data can be obtained on sheet materials using a routine procedure requiring about the same time and care as a comparable tension test.

The development of the compression testing jig for sheet materials discussed in this paper came as a result of a search for a more satisfactory method of making compression tests of steels used in structures. The expanded use of certain steels for load-bearing members soon revealed that tension tests alone are not always an adequate index of strength when the material is subjected to large compressive stresses.

For instance, the austenitic stainless steels become quite anisotropic when strengthened by cold rolling. Such steels do not have equal compressive and tensile properties, and these inequalities are further complicated by variation of the stress-strain characteristics with respect to grain direction **(1)**.[2] Cold rolling also imparts similar inequalities in low-carbon mild- and high-strength steels, but to a lesser degree. In fact, most metals which have been processed by mechanical working exhibit some anisotropy depending on the exact composition of the metal, together with the particular nature of processing with respect to working as by hot or cold rolling and possibly accompanied by annealing.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 688.

This is why there is a definite need for convenient methods of evaluating the mechanical properties of materials suspected of being anisotropic.

The determination of tensile properties of sheet materials has already reached a high degree of standardization. However, no particular method of determining compressive properties in sheet material has gained widespread acceptance to the extent that standard procedures can be established. All the methods for determining compressive properties of thin sheet material must have some means of supporting the specimen against buckling sc that the yield strength can be developed during a test.

The "pack" method introduced by Aitchison and Tuckerman (**2**) obtains lateral support in the weak, thickness direction by means of sufficient number of pieces of the same material stacked on both sides of one wider specimen on which the strain gages act. The entire pack is loaded during the tests. In a later modification the laminations were cemented with shellac (**3**). The outside laminations are supported by means of a system of rods braced by an exterior framework. The pack method has been used successfully in large scale testing of austenitic stainless steel at the National Bureau of Standards (**4**). Probably the most serious disadvantage of the pack method for research investigations is the relatively large machined specimen that must be prepared. Furthermore, pack specimens of thin and strong materials tend to buckle notwithstanding somewhat elaborate support.

The cylinder method of Franks and Binder (**5**) makes use of a tube rolled from a small blank of the sheet material to be tested, the ends of which are turned and ground preparatory to end loading during the compression test. Such cylinders are prevented from buckling locally by maintaining a certain maximum diameter-to-thickness ratio. Primary buckling is prevented by maintaining a certain maximum length-to-diameter ratio. The cylinder method is satisfactory for certain materials from a testing standpoint (**5, 6**). The principal objection to the use of the cylinder is the cold working that the specimen must undergo in forming a satisfactory cylinder, which introduces uncertainties as to the mechanical state of the metal. Metals that have already been severely cold rolled are probably not seriously affected by the forming of the cylinder, so that reliable results can be obtained. However, annealed mild or low-alloy steels lose their sharp yield points when formed into cylinders, which changes their stress-strain characteristics considerably. Annealing of such cylinders may restore sharp yield points but not necessarily the other initial properties. Furthermore, the joint along the cylinder cannot always be soldered conveniently.

A single-strip method of obtaining compression data was proposed by W. P. Montgomery to members of the Aluminum Research Laboratories at New Kensington, Pa. This led to the development of a device for supporting a single specimen 0.020 in. or greater for aluminum machined 2.63 in. long by 0.62 in. wide (**7**). Actual support of the specimen comes from rows of 0.093 in. diameter rollers spaced 0.100 in. apart along both faces of the specimen. The rollers react against straight guides and are held in place by flexible brass strips. A somewhat extensive series of compression tests were made in 1943 in the Armco Research Laboratories using a Montgomery-Templin compression jig as devised by Baldwin-Southwark.

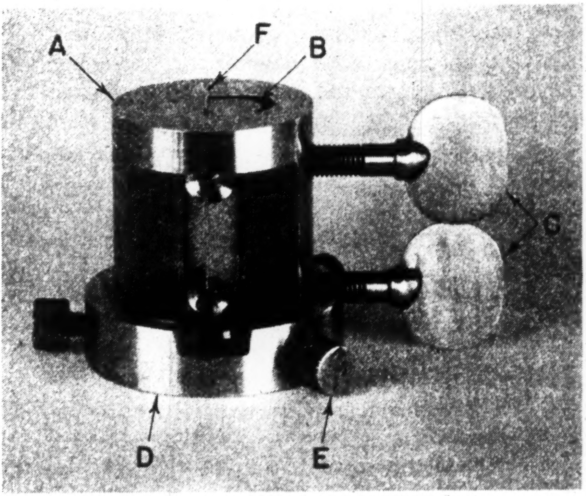

Fig. 1.—Assembled Single-Strip Compression Jig.

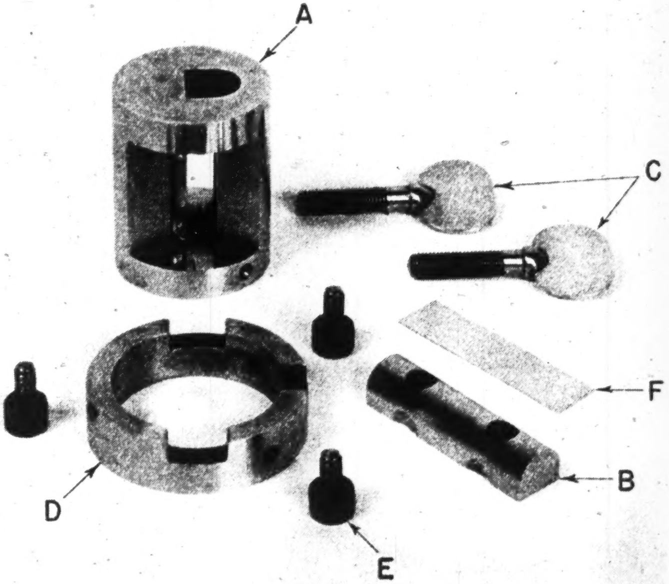

Fig. 2.—Showing Parts of Single-Strip Compression Jig.

These tests were made on steels having a wide range of strength and included the strongest of those described later in this paper. Buckling of the specimen ends occurred in most of the 0.010-in. thick steels having high yield strengths that were tested in the jig proposed by Montgomery, even when the rollers were tightly clamped. There was a tendency for the rollers to indent the specimen.

The jig described in this paper was developed in the Armco Research Laboratories with the intent of overcoming some of the drawbacks that seem evident in the above-described methods. Since the time this development occurred, the authors have learned of independent work done at the National Bureau of Standards for the Navy Bureau of Aeronautics (**8**) in which a Montgomery jig was fitted with flat guides in place of rollers. Tests made with both types of support gave practically identical results in tests on aluminum alloy 24S-RT.

A similar compression test for single pieces of sheet material has been presented by Jackman (**9**). In this test the specimen is a punching measuring 3.125 by 1 in. with two tabs on the long side for application of Southwark-Templin autographic strain recording equipment working on a 2-in. gage length. The specimen discussed by Jackman is supported between wood or metal side plates. One weakness of the method presented by Jackman is that strain observations are made along only one side so that eccentricity of loading with respect to the width cannot be detected at the time of testing.

Description of Jig

The single-strip compression jig developed by the authors is shown assembled in Fig. 1 and as taken apart in Fig. 2. The parts, all of which are tool steel, were machined to size, hardened, then ground to final dimensions. The jig body, *A*, was machined from a solid piece to provide an internal flat surface against which the specimen, *F*, is pressed by means of a flat-faced block, *B*, using screws *C*. The body *A* and the block *B* are dimensioned so that the 0.500-in. faces supporting the specimen are even with its edges. However, these faces are recessed about 0.025 in. at two positions for Huggenberger tensometer knife-edges which then rest along the specimen edges, without interference with the jig. The positioning ring *D* is fastened to the jig body *A* by means of screws *E* resting in conical seats which locate the jig body accurately 0.050 in. above a flat loading head. The jig body is made 1.900 in. long, thus giving complete support to the specimen along the same length. Specimens 0.020 in. and thicker are machined 0.500 in. wide by 2.000 in. long so that the specimen protrudes 0.050 in. from each end of the jig body. However, specimens thinner than about 0.015 in. with high yield strengths sometimes buckle at the jig ends. Specimens 0.010 to 0.020 in. thick cut 1.950 in. long are positioned so that only 0.025 in. stubs protrude from the jig body, and a platen with an annular recess 0.025 in. below its surface locates the positioning ring properly for these shorter specimens.

Large strains can be obtained in this jig because both ends of the specimen project adequately from the jig body.

Sample Preparation

The compression specimens are made to the dimensions shown in Figs. 3 (*a*) and (*b*). Usual tolerances for tension test specimens[3] apply except that the ends must be ground parallel within

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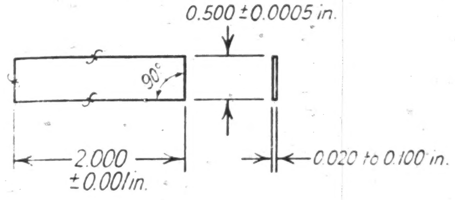
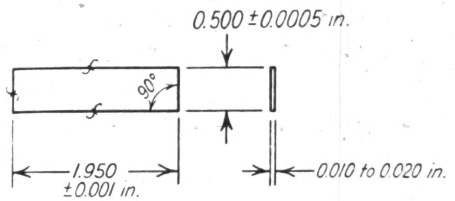
[3] The tolerances used in the Armco Research Laboratories are ±0.0005 in. on width of 0.500-in. wide sheet tension specimens and parallel within 0.00025 in. over a 2-in. long gage length.



(a) Steel thicknesses between 0.020 and 0.100 in.



(b) Steel thicknesses between 0.010 and 0.020 in.

FIG. 3.—Finished Dimensions of Single-Strip Compression Specimens.

0.0001 in., otherwise eccentricity caused by nonparallel ends affects the stress-strain curve obtained, especially above the elastic limit.

Blanks are usually sheared about $\frac{1}{8}$ in. oversize in both dimensions, then are stacked $\frac{1}{2}$ to 1 in. high and milled longitudinally to sizes indicated in Fig. 3. The ends of each sample are ground individually in a special clamp fixture, which grips the specimen most of its length like the testing jig. This is important; for otherwise a slightly curved specimen may be ground with edges parallel with respect to width but not to thickness, thus resulting in eccentricity that may cause buckling before the yield strength stress is attained.

TESTING PROCEDURE

The following steps are taken in making 1-in. Huggenberger tests with the single-strip compression jig developed by the authors:

1. Coat sides of specimen lightly with graphite grease or oil.
2. With the positioning ring in place, insert specimen in jig which should rest on the platen.
3. Tighten thumb-screws with moderate pressure.
4. Affix Huggenberger tensometers which have been previously adjusted to give the required number of minor resets.
5. With assembly resting on the pla-

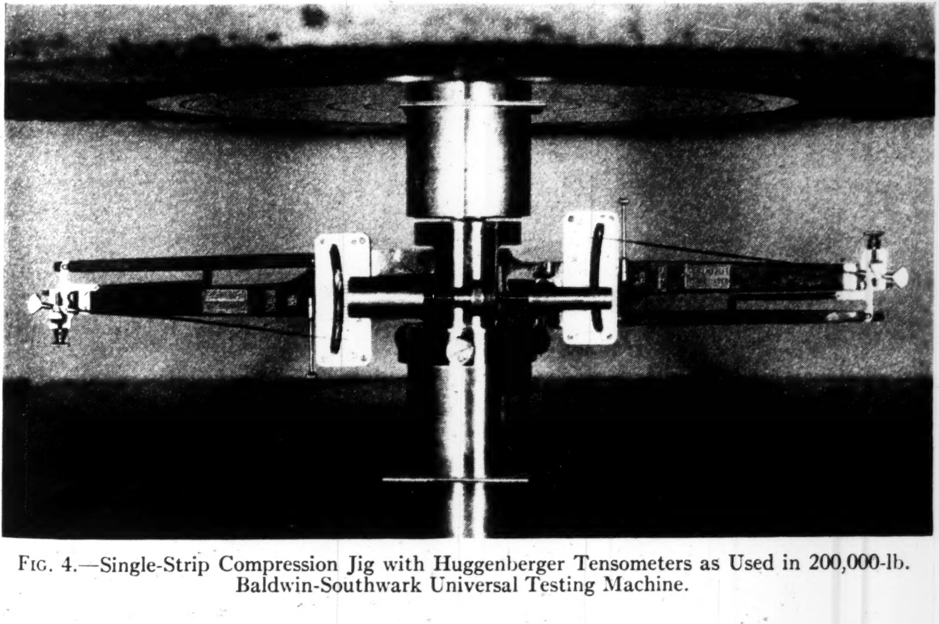


FIG. 4.—Single-Strip Compression Jig with Huggenberger Tensometers as Used in 200,000-lb. Baldwin-Southwark Universal Testing Machine.

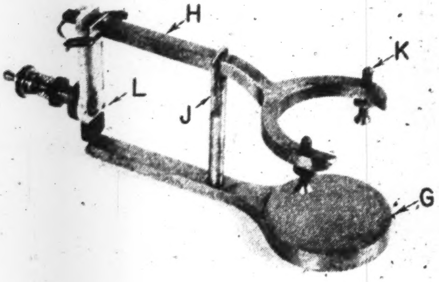


Fig. 5.—Compressometer for Autographic Load-Strain Diagrams of 2-in. Long Compression Specimens.

ten, release thumb-screws to check clearance of strip and gages with respect to the jig body.

6. Rock the specimen into the normal position with respect to the platen, then tighten thumb-screws moderately.

7. Set the assembly in the testing machine between the platens resting against wet blotting paper and preload the specimen 25 to 100 lb.

8. Set the Huggenberger tensometers for compression observations.

9. Release the positioning ring screws nearest to the thumb-screws first, followed by the remaining screw.

10. Load by convenient increments and make corresponding strain observations until the required load-deformation data are obtained.

11. If the first increment or so produces widely divergent readings in the opposite gages, the load is being applied eccentrically with respect to specimen width. The load should then be released and some of the blotting paper rubbed away at the appropriate side until the opposite gages produce similar readings.

The final arrangement of apparatus is shown in Fig. 4. The Huggenberger gages are more satisfactory for determining modulus of elasticity than the compressometer method yet to be described. However it is eminently suited for observations of offset yield strengths.

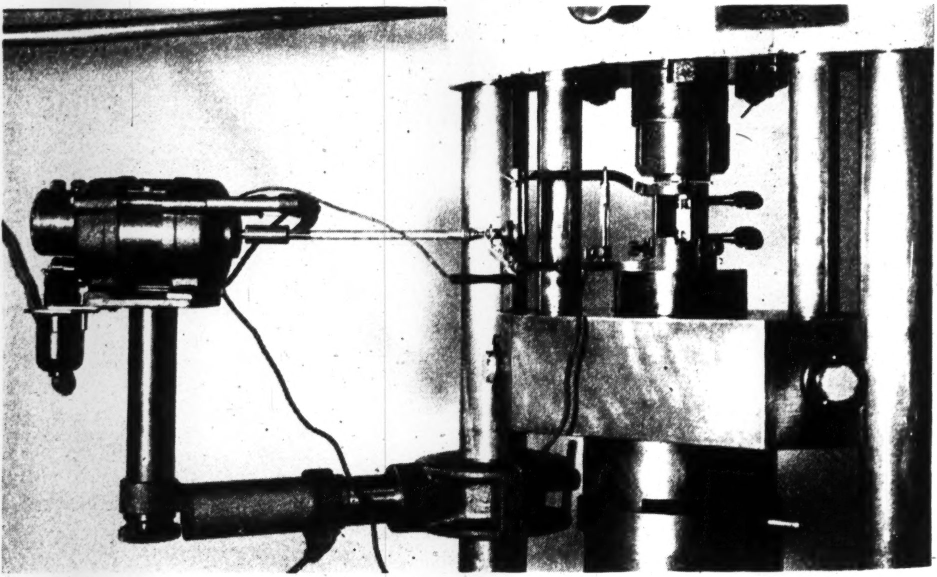


Fig. 6.—Single-Strip Compression Jig as Used with Compressometer and Templin Recorder in 20,000-lb. Amsler Universal Testing Machine.

AUTOGRAPHIC COMPRESSOMETER

The device which the authors identify as a "compressometer" is a modification of the Peters electric extensometer and is shown in Fig. 5. The compressometer consists of a banjo-shaped pad, *G*, upon which the compression jig rests. The compressometer has over-all magnifications of 250 and 500 when used with a Templin-type stress-strain recorder. This is accomplished by means of a 1:1 horizontal lever *H* which is pivoted on a ball-support, *J*. The forked ends probe both sides of the bottom surface of the platen through screws *K*. Vertical movement of the back end of lever *H* causes a 5:1 vertical lever *L* to move an electrical contact, the other half of which is mounted to a screw (50 threads per inch) driven by means of a Selsyn motor actuated by means of a Templin recorder (see Fig. 6). The compressometer averages the vertical movement of the platen at opposite edges of the specimen, so that the average strain in the specimen is observed.

Elastic deformation of the material of the platens is caused by local pressure of the specimen ends. The compressometer indicates deformations which are too large by the amount the platens are indented by the specimen. A small correction must be applied to the observed autographic curve. The correction is made by using the method given in Appendix I.[4]

COMPARISON WITH UNSUPPORTED SPECIMENS

The comparison of single-strip test values with those obtained on unsupported specimens of the same material provides a means of evaluating the influence of support friction on single-strip data. A $\frac{3}{4}$ by 2 by 12-in. bar of S.A.E. 4330 steel was heat treated to a hardness of 200 Brinell to give a yield strength slightly exceeding 75,000 psi. Hardness surveys revealed the bar to be uniform. Single-strip specimens were machined from the bar in the following thicknesses: 0.100, 0.054, and 0.035 in. Solid cylinders $\frac{1}{2}$ in. in diameter and 2-in. long were machined from the same bar for unsupported tests. The length of the cylinders was made 2 in. so that the compressometer could be used for autographic curves on these cylinders. The Tentative Methods of Compression Testing of Metallic Materials (E 9 – 33 T)[5] recommends a medium length specimen with a length equal to three times the diameter and a long specimen of eight times. The cylinder used in these tests is therefore close to recommended proportions.

Stress-strain curves obtained with Huggenberger tensometers are shown in Fig. 7. Yield strengths and moduli of elasticity are given in Table I. These are compared on a percentage basis with cylinder values in the lower part of the table. The yield strengths of single-strip specimens were 1 to 2 per cent higher than the cylinder value when Huggenberger data are considered. Yield strengths obtained from autographic curves were moderately erratic ranging from +4.0 per cent to −4.0 per cent from a comparable cylinder value. However, even these variations are probably no greater than those observed between different types of tension specimens.

The moduli of elasticity obtained from Huggenberger data on single-strips were −0.7 to +6.7 per cent from the cylinder value, and autographic values were similarly −1.2 to −8.3 per cent. The difficulty of checking modulus of elasticity due to unavoidable eccentricity may account for some of these variations from Huggenberger values. The consistent trend of lower moduli in single strips when data were taken from autographic curves appears to have been due to seating and premature yielding of the end material, which is of course observed for the entire specimen length. The Huggenberger data were essentially free from these defects due to the short 1-in. gage length.

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[4] See p. 687.

[5] 1944 Book of A.S.T.M. Standards, Part I, p. 1954.

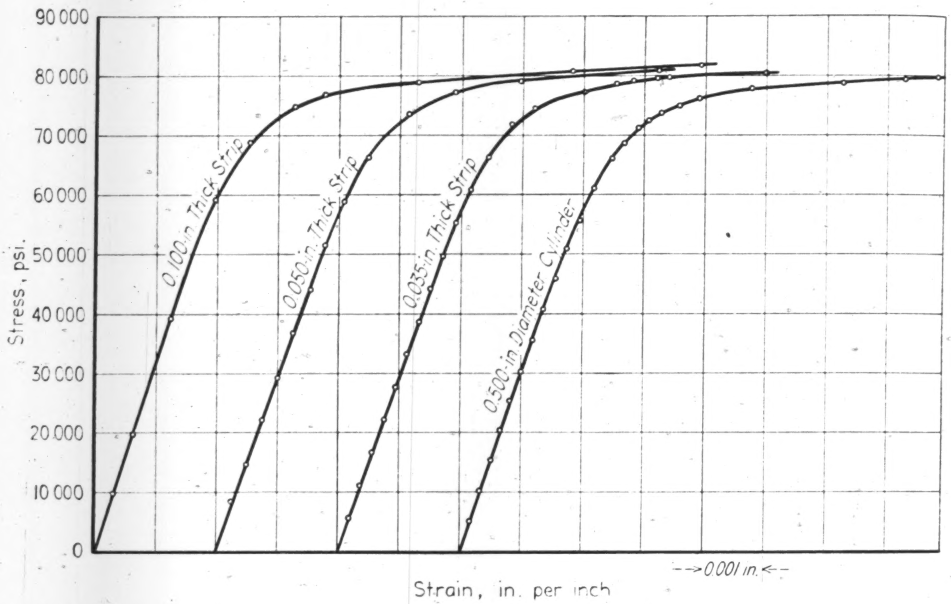


Fig. 7.—Comparison of Stress-Strain Curves from Single-Strip and Unsupported Solid Cylinder Tests on Specimens from a Homogeneous Bar of S.A.E. 4330 Steel.

TABLE I.—COMPRESSION TESTS OF SPECIMENS CUT FROM A BAR OF S.A.E. 4330 STEEL, BRINELL HARDNESS—200

Sample Size	Method of Test	Specimen	Test Data			
			Yield Strength, 0.2 per cent Offset, psi.		Initial Modulus of Elasticity, psi.	
			Huggen-berger	Auto-graphic	Huggen-berger	Autographic
2 x 0.500 x 0.100 in.	Single-strip compression jig	No. 1	78 200	80 100	32 000 000	29 500 000
		No. 2		78 300		29 900 000
2 x 0.500 x 0.054 in.		No. 1	79 000	79 100	29 800 000	31 300 000
		No. 2		84 400		30 900 000
2 x 0.500 x 0.035 in.		No. 1	79 000	77 900	29 500 000	31 800 000
		No. 2		81 700		31 800 000
2 x 0.500 in. diam.	Solid cylinder		77 500	81 200	30 000 000	32 200 000
			Difference with Respect to Solid Cylinder, per cent			
2 x 0.500 x 0.100 in.		No. 1	+1.0	−1.3	+6.7	−8.3
		No. 2		−3.5		−7.1
2 x 0.500 x 0.054 in.		No. 1	+2.0	−2.5	−0.7	−2.7
		No. 2		+4.0		−4.0
2 x 0.500 x 0.035 in.		No. 1	+2.0	−4.0	−1.7	−1.2
		No. 2		+0.8		−1.2

The above comparison indicates that

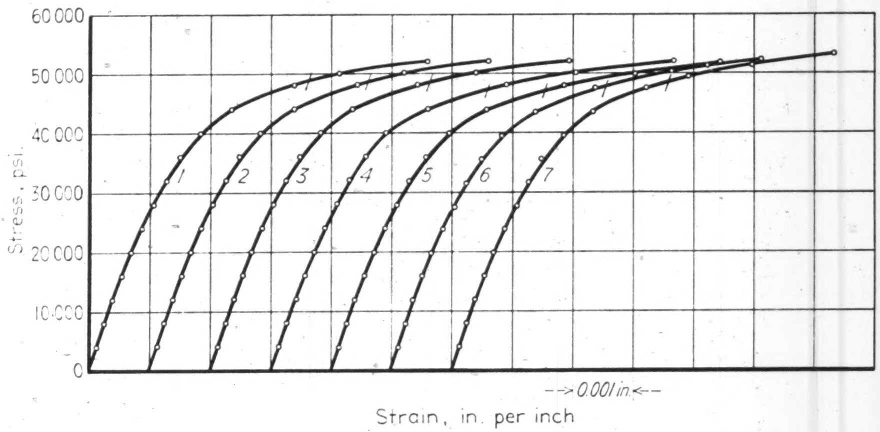


FIG. 8.—Seven Compression Stress-Strain Curves for Identical Specimens of Temper-Rolled 0.050-in. Armco High Strength Steel (50Y).

TABLE II.—COMPARISON OF YIELD STRENGTH AND INITIAL MODULI OBTAINED FROM COMPRESSION TESTS ON SEVEN IDENTICAL SPECIMENS OF 0.050 IN. ARMCO HIGH STRENGTH STEEL (50 Y) USING HUGGENBERGER TENSOMETERS.

Specimen	Yield Strength, 0.2 per cent offset, psi.	Initial Modulus of Elasticity, psi.
No. 1	48 800	30 600 000
No. 2	48 600	30 800 000
No. 3	48 600	30 100 000
No. 4	47 400	30 000 000
No. 5	47 300	30 500 000
No. 6	48 000	31 000 000
No. 7	48 600	30 800 000
Avg.	48 200	30 540 000
	Difference from Average, per cent	
No. 1	+1.2	+0.2
No. 2	+1.0	+0.8
No. 3	+1.0	−1.5
No. 4	−1.5	−1.9
No. 5	−1.8	−0.2
No. 6	−0.4	+1.4
No. 7	+1.0	+0.8

TABLE III.—MATERIALS TESTED.

Thickness, in.	Steel	State
0.050 0.050	ARMCO high strength (50Y)	Temper rolled Annealed
0.030 0.010	S.A.E. X-4110	Cold rolled
0.030 0.010	ARMCO high strength (50Y)	Cold rolled
0.022	ARMCO high tensile stainless type 301	Full hard temper

friction of the solid guides probably does not affect the single-strip test detrimentally.

PRECISION

A series of single-strip tests were made on seven identical specimens of the same material in order to establish the range of uncontrollable variation of the single-strip compression test. Temper-rolled Armco high-strength steel (50Y) in No. 18 gage tested along the longitudinal direction was used because its nonlinear stress-strain curve provides conditions which must be met in practical testing of commercial steels. The stress-strain curves are shown in Fig. 8, and salient values are listed in Table II. The yield strengths at 0.2 per cent offset ranged from 47,300 to 48,800 psi., averaging 48,200 psi. and corresponding to a variation of −1.8 to +1.2 per cent. The initial modulus of elasticity ranged from 30,000,000 to 31,000,000 psi., averaging 30,540,000 psi., and corresponding to a variation of −1.9 to +1.4 per cent. These results indicate that the single-strip compression test gives essentially the same strength and elasticity values on successive specimens, and therefore

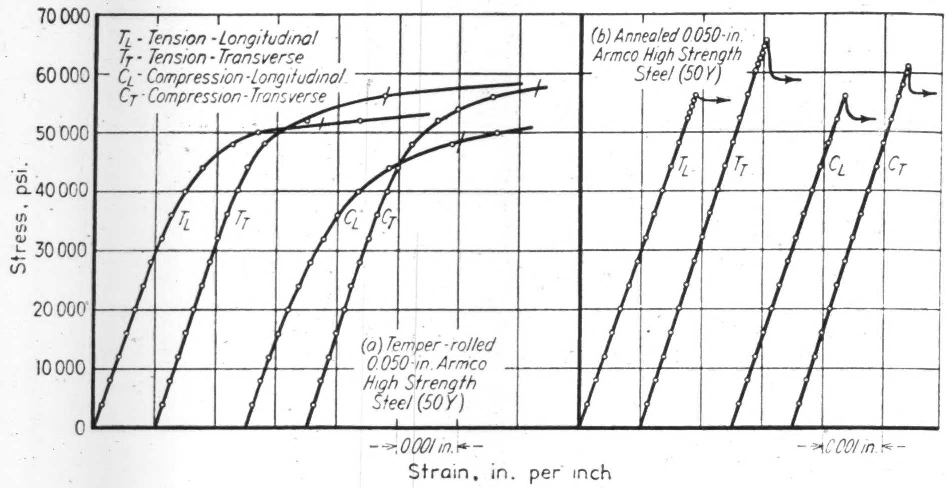


FIG. 9.—Tension and Compression Stress-Strain Curves.

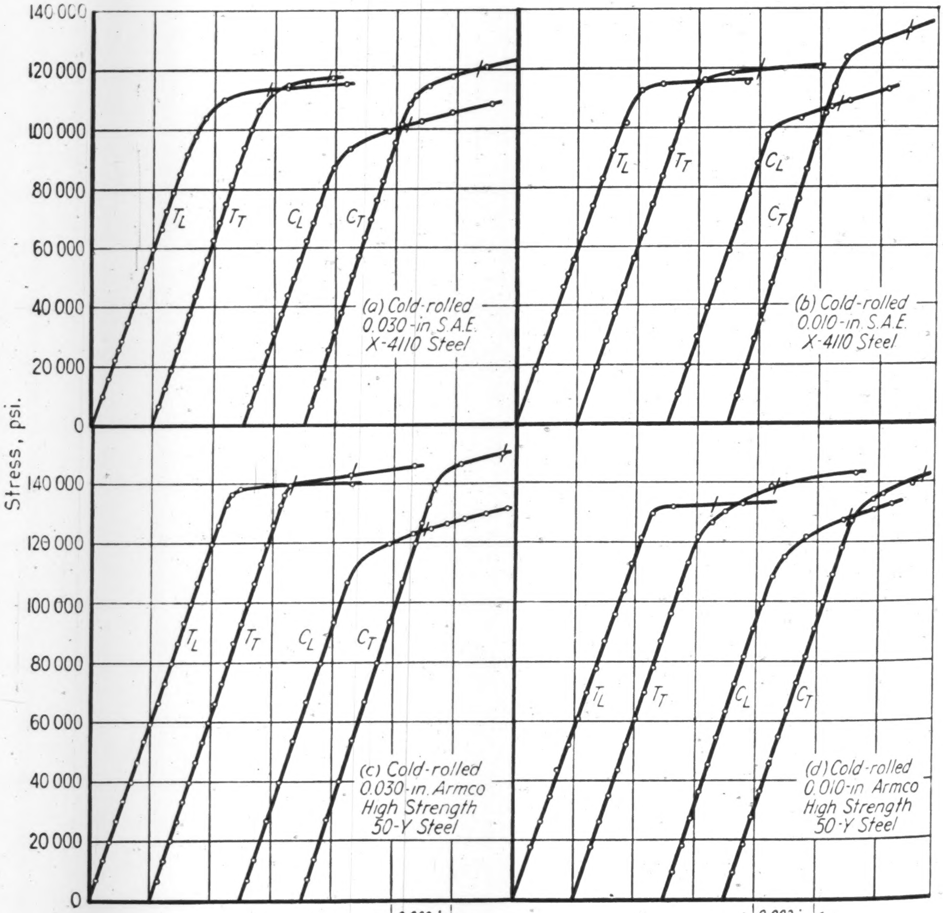


FIG. 10.—Tension and Compression Stress-Strain Curves.

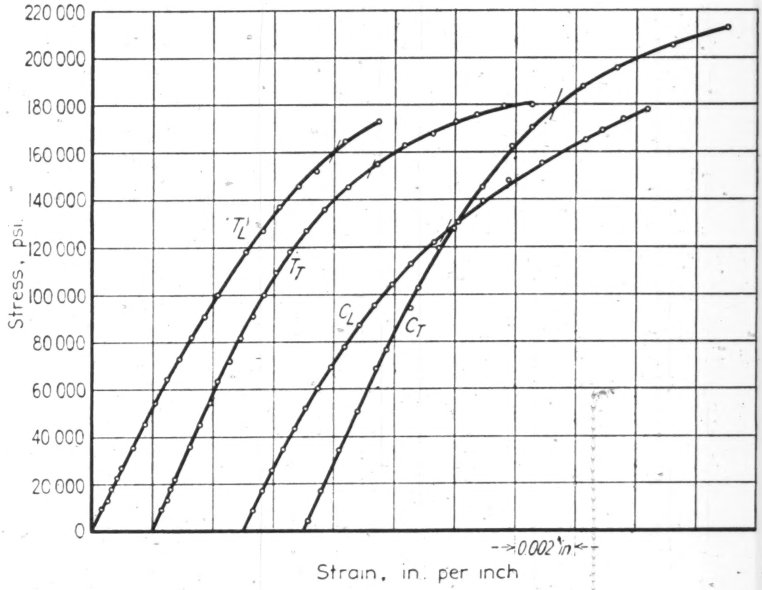
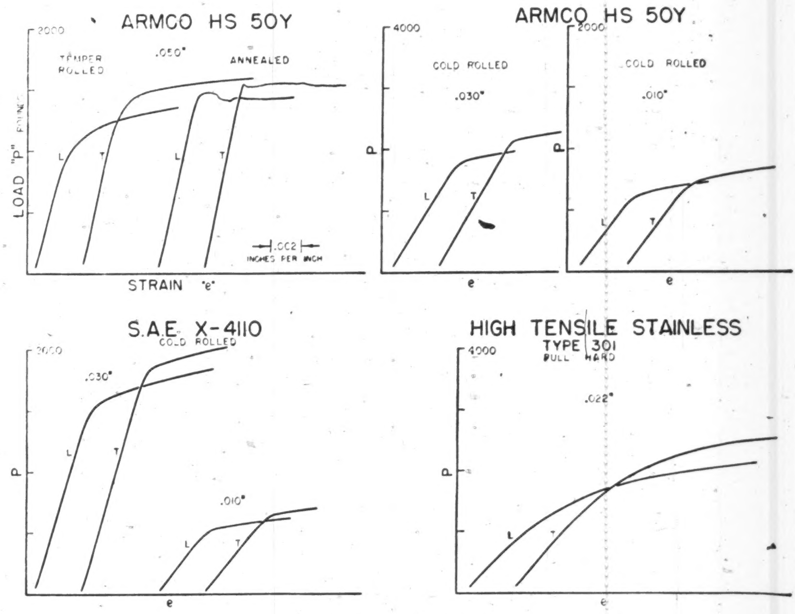


FIG. 11.—Tension and Compression Stress-Strain Curves for Full Hard 0.020-in. Armco High Tensile Stainless Steel-Type 301.



All Strains to the Same Scale.

FIG. 12.—Typical Autographic Load-Strain Curves Using Compressometer with Single-Strip Compression Jig.

TABLE IV.—YIELD STRENGTHS AND MODULUS OF ELASTICITY FOR VARIOUS STEELS OF HIGH YIELD STRENGTH.

Material	Nominal Thickness, in.	Test Direction	Individual Yield Strength and Initial Modulus of Elasticity						Average Yield Strength and Initial Modulus of Elasticity											
			Tension		Compression				Tension				Compression							
					E_0^a		Y.S.^{b}		E_0^a		Y.S.^{b}		E_0^a				Y.S.^{b}			
			E_0^a	Y.S.^{b}	Huggenberger	Autographic	Huggenberger	Autographic					Huggenberger		Autographic		Huggenberger		Autographic	
										Per cent Dev.		Per cent Dev.		Per cent Dev.		Per cent Dev.		Per cent Dev.		Per cent Dev.
Armco high strength (50Y) temper rolled	0.050	Long.	29.4 30.0	52.2 52.0	32.5 31.2	23.6 23.4	48.5 48.3	48.7 50.4	29.7	1.1	52.1	0.2	31.8	2.0	23.5	0.4	48.4	0.2	50.0	0.7
		Trans.	32.0 31.6	57.1 56.4	32.2 32.0	26.2 25.8	57.4 58.1	60.7 60.0	31.8	0.6	56.7	0.6	32.1	0.3	26.0	0.8	57.7	0.6	60.3	0.6
Armco high strength (50Y) annealed	0.050	Long.	29.8 29.8	55.3 56.5	30.3 29.5	25.7 25.7	57.0 56.8	56.5 56.5	29.8	0	55.9	1.1	29.9	1.3	25.7	0	56.9	0.2	56.5	0
		Trans.	32.0 32.2	58.1 58.8	33.0 33.0	29.0 28.1	61.6 60.0	60.5 61.2	32.1	0.3	58.7	0.1	33.0	0	28.5	1.6	60.8	1.3	60.8	0.6
S.A.E. X-4110 cold rolled	0.030	Long.	29.7	113.5	29.8 31.0	28.7 29.2	115.0 112.0	111.6 106.7	29.7	. . .	113.5	. . .	30.4	2.0	28.9	0.9	113.5	1.3	109.2	2.2
		Trans.	31.2	117.0	32.4 32.5	30.7 30.8	125.8 120.2	125.7 125.0	31.2	. . .	117.0	. . .	32.4	0.3	30.7	0.3	123.0	2.3	125.3	0.3
	0.010	Long.	29.2	115.0	31.5 29.8	31.6 29.8	112.6 107.8	110.5 112.0	29.2	. . .	115.0	. . .	30.6	2.4	30.7	2.6	110.2	2.2	111.2	0.7
		Trans.	30.0	119.0	33.5 31.5	29.4	132.5 B	129.5	30.0	. . .	119.0	. . .	32.5	3.1	29.4*	. . .	132.5*	. . .	129.5*	. . .
Armco high strength (50Y) cold rolled	0.030	Long.	30.0	139.8	30.1 30.6	29.9 30.0	125.6 124.0	127.0 126.0	30.0	. . .	139.8	. . .	30.3	0.8	29.9	0.2	124.8	0.6	126.5	0.4
		Trans.	31.0	143.8	32.3 32.1	31.6 30.2	153.7 149.8	148.8 147.8	31.0	. . .	143.8	. . .	32.2	0.3	30.9	2.3	151.7	1.2	148.3	0.3
	0.010	Long.	29.4	132.0	31.6 32.1	29.4 29.6	128.0 122.2	122.2 121.7	29.4	. . .	132.0	. . .	31.8	0.8	29.5	0.3	125.1	2.3	121.9	2.0
		Trans.	30.4	139.0	31.1 31.0	30.8 30.5	141.0 142.0	142.2 141.6	30.4	. . .	139.0	. . .	31.0	0.3	30.6	0.5	141.5	0.3	141.9	0.2

Armco high tensile stainless type 301, full hard	0.020	Long.	26.4	160.0	27.0 28.2	24.5 25.0	131.0 133.0	133.2 136.8	26.4	...	160.0	...	27.6	2.2	24.7	1.1	132.0	0.8	135.0	1.3
		Trans.	29.0	154.0	28.3 29.5	27.2 27.8	179.5 179.5	187.2 182.0	29.0	...	154.0	...	28.9	2.1	27.5	1.1	179.5	0	184.6	1.4
Average														1.21		0.83		1.01		0.82

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[a] E_0 = Modulus of elasticity, million psi.
[b] Yield strength at 0.2 per cent offset, thousand psi.
• Single value.
B = Buckled before yield strength was developed.

can be regarded as sufficiently precise for the determination of compressive properties of commercial high strength steel.

TYPICAL TENSION AND COMPRESSION DATA

Stress-strain curves were determined both in tension and compression for longitudinal and transverse specimens of the steels listed in Table III.

Tension tests were made on standard rectangular test specimens with a 2-in. gage length.[6]

The compression tests were run in duplicate using both Huggenberger tensometers and the autographic compressometer. Stress-strain curves for one specimen of each steel are plotted in Figs. 9 through 11. Autographic curves are shown in Fig. 12. Yield strengths and modulus of elasticity are given in Table IV.

The steels tested range in yield strength from approximately 50,000 to 160,000 psi. on the basis of tension tests. It may be reasoned that if such steels as these could be tested satisfactorily despite the general tendency to buckle, especially when the material is thin, then weaker materials probably would not present any particular testing problem from these standpoints.

The average values in Table IV were obtained from two individual values in each condition. The deviations represented are also listed. The averages of the deviations for modulus of elasticity were 1.2 and 0.8 per cent for Huggenberger and compressometer measurements, respectively. Average deviations of yield strengths were 1.0 and 0.8 per cent, respectively. Individual deviations for modulus of elasticity were as small as zero and as large as 3.1 per cent; yield strengths, zero to 2.3 per cent. Variations in tests on multiple specimens of the same material by other investigators, such as Templin (10), are of the same order of magnitude.

Compressometer measurements gave moduli of elasticity averaging 9.3 per cent lower than those obtained with Huggenberger tensometers. One reading was lower by 26.1 per cent. These large discrepancies probably were due to factors discussed in the following section. Yield strengths averaged 0.9 per cent higher, with compressometer measurements ranging from +4.5 to −3.8 per cent above and below corresponding Huggenberger observations. Even so, the compressometer gave yield strength values that would probably be sufficiently accurate for routine testing and moreover has the advantage of rapidity in testing.

Comparison of longitudinal and transverse mechanical tests in Table IV leads to evaluations of the degree of anisotropy. The Huggenberger data give comparable values for this purpose. The transverse moduli of elasticity were found to be 2.8 to 9.8 per cent greater than longitudinal values from tension tests. Transverse yield strengths in tension were similarly 3.8 less to 9.0 per cent greater than longitudinal values. Compression tests showed transverse moduli of elasticity to range between 2.5 per cent less and 10.3 per cent greater than longitudinal. Similarly, compression yield strengths ranged from 8.2 to 36.0 per cent greater than longitudinal values. Annealed Armco high-strength steel (50Y) had the least anisotropy, while full hard Armco high tensile stainless steel (type 301) had the most anisotropy of the materials tested in this investigation.

Comparison of compression and tension values reveals the necessity of the compression test for accurate structural data. The moduli of elasticity in compression from Huggenberger observations on longitudinal specimens ranged from 1.0 to 8.2 per cent greater than corresponding tension specimens. The corresponding values are 0.3 per cent less to 3.9 per cent greater when considering transverse specimens. Yield strengths in compression from Huggenberger observations ranged from 0.0 to 17.5 per cent lower than corresponding longitudinal tension specimens with values 1.8 to 16.5 per cent greater for transverse specimens compared in the same manner.

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[6] Standard Methods of Tension Testing of Metallic Materials (E 8 - 42), 1944 Book of A.S.T.M. Standards, Part I, p. 962.

Discussion

In the compression testing of specimens with flat ends there is an end effect which results from regions of large shear deformations diverging from the corners of the test specimen (11). This results in a symmetrical bulging of both ends of the specimen during test as schematically shown in Fig. 13. Bulging of this type was observed along the edges of the ends of specimens subjected to large plastic deformations. This condition is said to be somewhat alleviated by the use of lubricants such as graphite on the compression platens. The region affected by these large shear deformations at a maximum may be a distance from the end equal to the width. The affected area is a function of the specimen length, the shape of bearing area, and the amount of friction resulting from the lateral motion of the end of the specimen undergoing deformation. Both ends are affected a maximum distance of $\frac{1}{2}$ in. in the case of the 2-in. specimen used in this paper. This leaves the middle portion of 1 in., at the least, which is relatively unaffected by the end condition. Huggenberger data are obtained on the section of the test specimen which is essentially free of the errors mentioned and should give more accurate data.

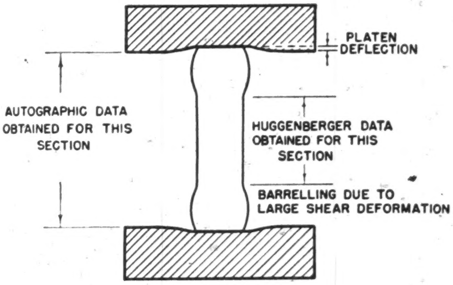
PLATEN DEFLECTION
AUTOGRAPHIC DATA OBTAINED FOR THIS SECTION
HUGGENBERGER DATA OBTAINED FOR THIS SECTION
BARRELLING DUE TO LARGE SHEAR DEFORMATION

Fig. 13.—Conditions Leading to Errors in Measurements (Exaggerated).

A longer specimen length could have been chosen to get a greater test section under uniform compression; and stress-strain data then taken over this longer test section probably would have given better values for modulus of elasticity. But limits on length of stub ends would reduce the degree of strain that could be obtained. An autographic extensometer could be attached to this test section to eliminate errors resulting from the end effect. Yet, these errors can be tolerated to obtain the advantage of greater ease of specimen preparation and testing for determinations of yield strength.

The modulus of elasticity derived from the autographic curves is also in error due to the deflection of the platen. A correction can be applied to the measurement. This correction has been worked out and appears in the appendix to this paper. It may amount to as much as 15 to 20 per cent and must be considered if the determination of the modulus of elasticity is to be obtained from the autographic curves. The excess deformation due to shear at the specimen ends is not taken into account in the above correction, and consequently moduli taken from autographic curves are still less than Huggenberger values.

The autographic curves have a slight curvature in the initial stages of loading. This may be the result of seating of the ends.

The autographic compressometer records the elastic deformation of the platens plus the total deformation of the specimen (see Fig. 13). Yield strengths obtained were satisfactory, even including the error due to the end condition, as may be seen by examination of the data in Table IV.

A source of error common to both methods of measurement is secondary buckling. This consists of numerous waves of very small amplitude throughout the length of specimens subjected to large strains (see Fig. 14). This condition is evident only in the thinner specimens and may be due to the clearance caused by the film of lubrication on the test specimen. It is believed that this effect is small and can be neglected.

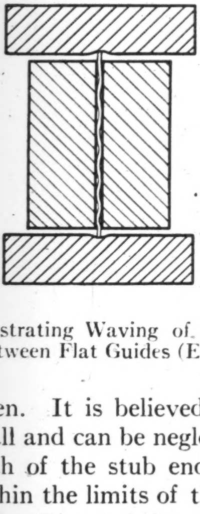

Fig. 14.—Illustrating Waving of Light Gage Specimens Between Flat Guides (Exaggerated).

The length of the stub ends may be changed within the limits of their buckling strength. The stub lengths used in this investigation were based on a tangent modulus of elasticity (1) of 4,000,000 psi. at the approximate yield strength of the material being tested. The stub end lengths were standardized on the strongest material tested. Shorter end lengths may be used providing the total length allows sufficient strain to obtain the necessary data.

Summary and Conclusions

1. The main purpose of the jig is to provide a flat-faced clamp which prevents buckling of the thin specimen and acts as a guide as the specimen is compressed.

2. The single-strip compression jig described in this paper makes possible rapid determination of large quantities of compression data in sheet steels of 0.010 to 0.100 in. in thickness. There is no local buckling in materials having yield strengths as high as 185,000 psi.

3. The positioning ring of the jig provides an accurate method of dividing the excess of specimen length between the opposite ends of the jig. It maintains the specimen in a vertical position until a small preload can be applied.

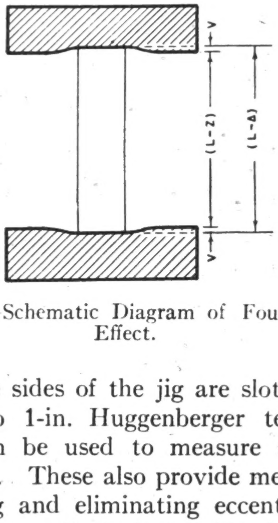

Fig. 15.—Schematic Diagram of Foundation Effect.

4. The sides of the jig are slotted so that two 1-in. Huggenberger tensometers can be used to measure strains correctly. These also provide means of observing and eliminating eccentricity.

5. The specimen is machined 0.500 in. wide by sheet thickness. Two lengths of 2.000 and 1.950 in. are used for 0.020 to 0.100 and 0.010 to 0.020 in. thicknesses, respectively. Ends are ground parallel within 0.0001 in.

6. The lengths of the two protruding ends are kept within certain limits, based on thickness and strength, so that the stress-strain data can be obtained without buckling of the specimen ends.

7. Data from single-strip compression tests made on thin specimens machined from a homogeneous bar of S.A.E. 4330 steel compared favorably with tests

made on solid cylinders machined from the same bar and tested without support.

8. Data from single-strip compression tests on seven identical specimens of high-strength steel had a maximum variation of 1.9 per cent from average values of yield strength and modulus of elasticity.

9. Duplicate tests made on a group of high yield strength steels produced maximum deviations averaging about 1 per cent.

10. Yield strength determinations using the compressometer device were within 4 per cent of corresponding Huggenberger values. The compressometer method of measuring compressive strains is much faster than the Huggenberger method and can therefore be regarded as a useful way of making routine yield strength determinations.

11. Nonuniformity of stress distribution near the ends of flat-faced compression specimens causes errors in the determination of the moduli of elasticity when the compressometer is used. However, the method used to correct for the elastic deformations of the platens is given.

12. Measurements using Huggenberger tensometers appear to be essentially free of the above-mentioned errors.

13. On the basis of comparisons between longitudinal and transverse specimens, the single-strip compression test reveals definite anisotropy in the cold-rolled steels tested. Differences in compression and tension values were observed which appear to be the result of the same anisotropy.

Acknowledgments:

The authors acknowledge the assistance of these associates: J. C. Young and Robert Easton for their collaboration in the design of the compressometer and for their faithful execution of the compression jig; Stanley Goodman for his care in preparing the specimens; Glenn Selby in the testing work; R. L. Kenyon and R. H. Heyer for advice in preparing the manuscript; and T. F. Olt and R. S. Burns for suggestions made in their review of this paper.

APPENDIX I

ELASTIC CORRECTION FOR FOUNDATION EFFECT OF AUTOGRAPHIC CURVES DETERMINED WITH THE COMPRESSOMETER.

Mathematical symbols:

P = Load in pounds.
w = Width of specimen in inches.
t = Thickness of specimen in inches.
Z = Recorded deformation in inches.
V = Deflection of foundation in inches.
L = Original length of specimen in inches.
Δ = Deformation of specimen in inches.
θ = Unit deformation or strain in specimen in inches per inch.
E = Modulus of elasticity in pounds per square inch.
ν = Poissons Ratio, 0.25.
A = Cross-sectional area in square inches.
F = Stress in pounds per square inch.
m = A function of the shape of the section.

From Fig. 15 it can be seen that

$$Z = \Delta + 2V \qquad (1)$$

The formula for deflection of an elastic foundation under pressure applied over rectangular areas is as follows (**12**):

$$V = \frac{mP(1 - \nu^2)}{E\sqrt{A}} \qquad (2)$$

From Eq. 2, let

$$K = \frac{m(1 - \nu^2)}{E\sqrt{A}} \qquad (3)$$

Let α be the width to thickness **ratio of** the compression test specimen,

$$\alpha = \frac{w}{t}$$

The quantity m which is a function of the shape of the cross-sectional area expressed in terms of α is given by Timoshenko (**12**) and is reproduced as follows:

TABLE OF FACTORS m

	Circle	Square	Rectangles with various α					
			1.5	2	3	5	10	100
m.......	0.96	0.95	0.94	0.92	0.88	0.82	0.71	0.37

Since $A = wt$, then K of Eq. 3 can be determined. Then,

$$V = KP \ldots\ldots\ldots\ldots\ldots (4)$$

Using Eqs. 1 and 4 we obtain

$$\theta = \frac{Z - 2KP}{L} \ldots\ldots\ldots\ldots (5)$$

$$E = \frac{F}{\theta} = \frac{PL}{A(Z - 2KP)} \ldots\ldots\ldots (6)$$

$$E = \frac{L}{A\left(\frac{Z}{P} - 2K\right)} \ldots\ldots\ldots (7)$$

This equation is used for the determination of modulus of elasticity from the autographic curves. Note that Z/P is the reciprocal of the slope of the autographic load-deformation curve.

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(**3**) C. S. Aitchison, "Extension of Pack Method for Compressive Tests," N.A.C.A. Report No. 789, 1940.

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(**9**) K. R. Jackman, "Improved Methods for Determining Compression Properties of Sheet Metal," *Automotive and Aviation Industries,* Vol. 90, No. 11, June 1, 1944, p. 36.

(**10**) R. L. Templin, "Some Factors Affecting Strain Measurements in Test of Metals," ***Proceedings,*** Am. Soc. Testing Mats., Vol. 34, pp. 182–201 (1934).

(**11**) A. Nadai, "Plasticity," 1st American Edition, pp. 108–125, McGraw-Hill Book Co., Inc., New York, N. Y., 1931.

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DISCUSSION

MR. J. R. TOWNSEND[1] (*by letter*).—The authors are to be commended for the development of an improved jig for determining the yield strength and modulus of elasticity of thin sheet materials under compression. We believe that the data presented by the authors indicate that the compression jig which they have developed is satisfactory for use in the inspection of thin sheet materials. The discussion presented by the authors in which they describe the behavior of the test specimens, when tested in their single strip compression jig with Huggenberger tensometers as compared to similar tests made in the same compression jig but with the compressometer used to give autographic data, we believe explains the low values of modulus obtained in the latter case. It would, no doubt, be possible to modify the jig so that autographic recorders could be used with the single strip compression jig. This would be a distinct advantage if many tests are to be run. It would also be interesting to know whether the authors have compared the results of tests made on their jig with those made recently by other investigators in which the specimen was supported in a manner similar to that used by the authors except that small recesses were left in the flats which support the test specimen. These recesses were then filled with grease to prevent lateral buckling of the test specimen without imposing excessive frictional forces on the test specimens.

We believe this field of investigation should be further explored by others to determine whether other materials evidence this same anisotropy as shown by the steels covered by this investigation.

MR. BAXTER C. MADDEN, JR.[2] (*by letter*).—The authors have presented information which should be emphasized: namely, that when considering the mechanical properties of certain sheet and strip materials in various directions with respect to the direction of rolling, the minimum compressive yield strength may be considerably lower than the minimum tensile yield strength. Since the criterion for the design of aircraft structures is often the compressive yield strength, it is important to know its minimum value. There has been a tendency among some materials producers to overlook the importance of compression testing of sheet and strip.

Regarding the testing procedure, item 3 states "Tighten thumb-screws with moderate pressure." Undoubtedly, different operators would use different pressures with the probability that excessive pressure would sometimes be applied. It has been shown[3] that considerable error in both yield strength and modulus of elasticity may occur in compression tests in which the manually adjusted initial supporting force is too large. Excessive supporting force may be the reason for the compressive yield strengths of the single thickness tests, determined by Huggenberger gages (Table I), being from 78,200 to 79,000 psi., while the solid cylinder value, tested without support and with Huggenberger gages, was 77,500 psi. Perhaps some simple addition to the jig could be devised which would limit, or indicate, the supporting force applied to the specimen.

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[1] Materials Engineer, Bell **Telephone Laboratories,** New York, N. Y.

[2] Major, Air Corps, Materials Laboratory, Engineering Div., Wright Field, Dayton, Ohio.

[3] J. N. Kotanchik, W. Woods, and R. Weinberger, "Investigation of Methods of Supporting Single-Thickness Specimens in a Fixture for Determination of Compressive Stress-Strain Curves," National Advisory Committee for Aeronautics Restricted Bulletin No. L5E15 (May, 1945).

MR. WM. R. OSGOOD.[4] (*by letter*).—The importance of the compressive properties of sheet materials is receiving increasing recognition, as attested by the numerous devices developed in recent years for determining those properties. The most recent one is the interesting and convenient jig described by Messrs. LaTour and Wolford. A few comments and questions suggested themselves in reading the paper:

How was the internal flat surface against which the specimen is pressed made flat after hardening?

Having the specimen project equally from both ends of the body of the jig may be very useful in obtaining the maximum possible strains on thin material. On the other hand, except for such material no advantage is apparent.

It seems to the writer that a specimen 2 in. long having a gage length of 1 in. is the very shortest specimen that should be used to avoid end effects. The writer would feel a little more comfortable if the specimen were $2\frac{1}{4}$ in., or preferably even $2\frac{1}{2}$ in. long. If the specimen is too long, the column effect in the plane of the specimen may introduce errors. It is necessary to compromise between these two effects: end effect and column effect.

Although the authors' wet-blotting-paper method may assure uniform strain at a low strain, even if the blotting paper is squeezed uniformly at higher strains, the nonparallel relative motion of the heads of the testing machine may introduce considerable variation in strain across the width of the specimen. The best way to overcome this difficulty, if it arises, is probably to use a subpress having a hollow plunger with a push rod transmitting the load to the plunger near the end of the plunger that is in contact with the specimen. If the screws of a screw-power machine are all alike and symmetrically situated relative to the center of the machine, and if the screws and the accompanying gears are accurately made, a subpress should not be necessary. Nor should a subpress be necessary with the conventional type of hydraulic machine if the ram is a good enough fit not to require packing, and if the upper head does not tilt under load.

The authors' jig is so stiff that it seems possible, if used for relatively thick specimens, at high strains the specimen may thicken enough (Poisson's ratio) to cause appreciable friction between it and the jig.

It is the writer's opinion that if any large number of autographic compression tests is to be made, an autographic compressometer should be designed that acts on a gage length free from end effects.

It should not be long before it is possible to buy commercially a jig for compressive testing of sheet metals that is comparable in convenience of handling to Templin grips for tension testing.

MR. R. L. TEMPLIN[5] (*by letter*).—The authors of this both excellent and timely paper have described testing apparatus and procedure the use of which apparently will result in satisfactory compressive properties of thin sheet materials. In so far as yield strength values are concerned, their conclusions are unquestioned. Before accepting their procedures for modulus of elasticity determinations, however, it would seem desirable, if not necessary, to know the errors in the strain measuring equipment used. The ability of deformation measuring apparatus to repeat values, the possession of good sensitivity, or both, does not connote accuracy although these items are necessary ones for accurate measurements. It is, therefore, suggested that strain measuring apparatus used in determining modulus of elasticity values of materials should be calibrated as indicated by Wilson[6] and others.[7]

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[4] **Materials Engineer, National Bureau of Standards, Washington, D. C.**

[5] **Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.**

The procedure recommended by the authors for correcting for out-of-parallelism of the testing machine platens, using wet blotting paper and finger dressing, might well be improved upon. For the type of testing machines used by the authors, corrections for errors in platen parallelism can be readily made with rather simple adjustable bearing blocks. One type of such blocks, as shown in the accompanying Fig. 1, is essentially comprised of two hardened steel disks, one surface of each being out of parallel with the other surface of the disk by a definite but relatively small amount. The disks are made so that when one is placed upon the other, with the thickest dimension of one opposite the thinnest of the other, the over-all thickness of the two will be constant. As one of the tapered disks is rotated upon the other, the assembly as a whole becomes a tapered disk. Suitable graduation of one quadrant of each disk in accordance with a cosine function, and provision of a small centering pin to maintain alignment during manipulation, result in a device which can be used to correct for errors in platen parallelism and is readily manipulated. In the Aluminum Research Laboratories we have constructed such adjustable bearing blocks to correct for maximum errors in parallelism of 0.001 to 0.0015 in. per inch of diameter. They have been graduated so that when the zeros of the two scales are opposite each other, the assembly will be parallel, and as like numbered graduations are turned to coincidence the total taper in the assembly corresponds to the graduations in coincidence. With the bearing fixture on the lower platen of the testing machine and the zeros in coincidence, the movable platen of the machine is set in the position that will be used in testing. The amount and location of the maximum out-of-parallelism between the surface of and near the perimeter of the bearing fixture and the other platen of the testing machine is then determined with screw or dial gage micrometer. If this amount be 0.003 in., for example, the graduations of the bearing fixture corresponding to this value are turned into coincidence and the whole bearing fixture turned so that the coincident graduations are at the location of maximum error just measured. Parallelism is then rechecked and if not within the desired limits further slight adjustment of the fixture is made. No further adjustment

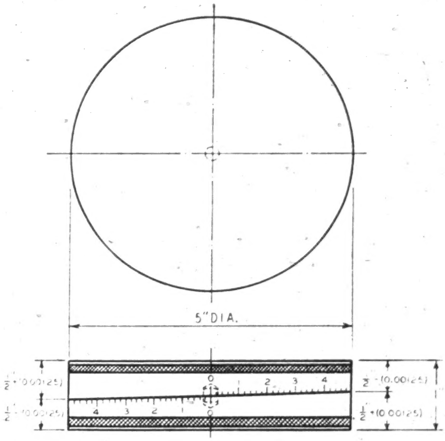
5"DIA.
$\frac{1}{2}$" + (0.00125)
$\frac{1}{2}$" - (0.00125)
$\frac{1}{2}$" - (0.00125)
$\frac{1}{2}$" + (0.00125)
0
1
2
3
4
0
1
2
3
4

FIG. 1.—Adjustable Bearing Block for Compression Tests of Materials.

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[6] B. L. Wilson, "Proposed Method of Verification and Classification of Strainometers," ASTM BULLETIN, No. 117, August, 1942, p. 83.

[7] R. W. Vose, "Characteristics of the Huggenberger Tensometer," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 862 (1934).

R. L. Templin, "The Calibration of Extensometers," *Proceedings*, Am. Soc. Testing Mats., Vol. 28, Part II, p. 714 (1928).

is required until the position of the adjustable platen on the screws of the testing machine is changed. For a series of compression tests of the kind described by the authors, the adjustment of the bearing fixture would be made only before starting the tests.

Referring to the "compressometer" described by the authors, one can readily appreciate that the device is easier to manipulate than the two Huggenberger tensometers. In 1943 an autographic strain-follower was designed and built in the Aluminum Research Laboratories as shown in the accompanying Figs. 2 and 3. This strain gage has a 1-in. gage length, a lever magnification of 4× (over-all 250×, 500×, or 1000×) and weighs 0.57 oz. It is easily and quickly applied to a thin sheet compression speci-

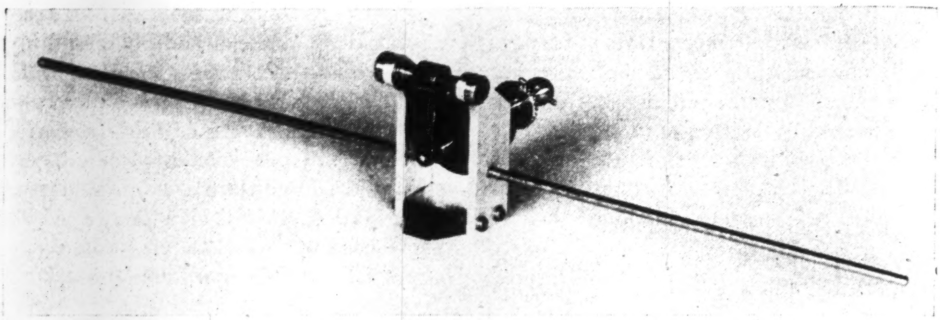

FIG. 2.—One-inch Gage Length Strain Follower for Use with Templin Autographic Apparatus in Compression Tests of Materials.

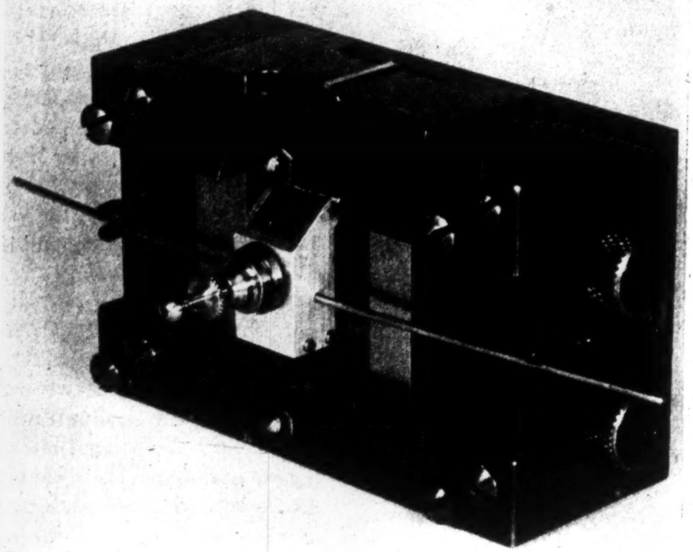

FIG. 3.—Assembly of 1-in. Autographic Strainometer with Montgomery-Templin Compression Testing Jig for Thin Sheet Specimens.

men by merely pushing the ends of the spring wire, fixed in the frame of the strain-follower, into the two spring clips on the Montgomery-Templin jig. Connection with the autographic apparatus is then made as in the case of the compressometer described by the authors.

Calibration of this strain-follower has been made using a long round tension specimen on which two Tuckerman optical strain gages were mounted opposite each other and the autographic strain follower in line with and adjacent to one of the Tuckerman gages. The specimen was strained through ball and socket adapters in a Baldwin Southwark Testing Machine of 500–5000–50,000-lb. capacity, which had been carefully calibrated using apparatus certified by the National Bureau of Standards. The Tuckerman gages had likewise been calibrated by the National Bureau of Standards. Use of the two Tuckerman gages permitted a determination of the magnitude of nonuniformity of strain in the calibration specimen and location of the autographic strain gage adjacent and in line with one of the Tuckerman gages permitted a direct comparison to be made between these two types of strain measuring apparatus.

The Tuckerman gage readings differed by not more than 0.6 per cent, and the autographic strain gage in five successive runs showed variations from the adjacent Tuckerman gage ranging from −0.2 per cent to +0.6 per cent, average +0.12 per cent.

This autographic strain gage measures strain on only one edge of the specimen, and this has been cited by the authors as a criticism of the method used by Jackman (reference **9**). As previously pointed out in reference **10**, noted by the authors, if uniform axial loading of a compression specimen can be accomplished within acceptable limits, strains need be measured on only one element of the specimen. The authors have used the two Huggenberger tensometers to check the correction for out-of-parallelism of the testing machine platens and perhaps also to a negligible extent in view of the limits they have imposed on the machining tolerances, for checking the errors in the parallelism of the ends of the specimen.

It is suggested that if the parallelism of testing machine platens can be brought within limits corresponding to those indicated for the test specimens by the authors, there is no need for strain measuring apparatus on more than one of the edges of the specimen. Furthermore, the autographic strain measuring device just described and used as shown in Fig. 3 would give results in all probability as good as those obtained by the authors using Huggenberger tensometers and may well be more readily manipulated than the compressometer they have described. Certainly the apparatus has given very satisfactory results in compression tests of thin sheet aluminum in our laboratories ever since it was put into service eighteen months ago.

In most of these compression tests, only yield strength values are of interest. Furthermore, we have been able to correct out-of-parallelism of our testing machine platens within acceptable limits for aluminum specimens so that the use of an adjustable bearing block is unnecessary for satisfactory yield strength determinations using the autographic device described. It is appreciated, however, that an adjustable bearing block is needed for the more precise tests.

MR. G. WELTER[8] (*by letter*).—In connection with the above paper, I should like to draw the attention of the authors to my paper in the 1944 *Proceedings* entitled "Micro-Deformation under Tension and Compression Loads of Thin

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[8] Professor of Applied Mechanics, Ecole Polytechnique, Montreal, Canada.

Aluminum Alloy Sheets for Aircraft Construction," presented at the 1944 Annual Meeting of the Society.[9]

This paper deals particularly with the same problem, that means the testing of single thin and flat specimens in compression, recording autographically the load-deflection curve. The main difficulties which the authors discuss in their paper have been avoided by this method.

It seems as if this paper did not come in due time to the attention of the authors.

MR. JAMES A. MILLER[10] (*by letter*).—We were very much interested in comparing the technique we have developed at the National Bureau of Standards with this independent work of LaTour and Wolford. The authors are to be congratulated in developing a convenient and successful method of testing sheet metal in compression. They have also made an excellent summary of the difficulties found in previously developed methods for compression testing of thin sheet metal. Their summary is in accord with our experience.

In continuing, at the request and with the support of the Bureau of Aeronautics of the Navy Department, the work at the National Bureau of Standards described in reference **8**, we have found that compression tests on sheet metal can be made with a simple fixture having solid guides with the same precision as pack tests or tests with the Montgomery-Templin fixture. Furthermore, tests could be made on thin high-strength sheet which we were not able to test by either of these methods. Our fixture and procedure are described briefly in a discussion of another paper.[11]

From these independent investigations it appears that fairly successful results can be obtained using fixtures with considerable differences in design. We wish, however, to discuss certain details of our test fixture and procedure which we think have some advantages over those described in the present paper.

In compressive tests of sheet materials it is desirable that sufficient lateral support be furnished to prevent premature buckling without introducing appreciable restraint to lateral expansion of the specimen. The increase of the thickness of sheet under axial load is restrained to some extent by the fixture either through the pins, rollers or guides according to the type of fixture. This lessens the axial compression under any given load and increases the apparent initial modulus of elasticity and affects even more the strain at high stresses at which plastic yielding occurs. This effect is greater for the thicker specimens. It may account for the high value of 32,000,000 psi. for the 0.100-in. thick specimen reported in Table I and for the strains of the single-strip specimens (Fig. 7) being noticeably less than those for the cylinder for stresses above 70,000 psi.

Because of this effect and also because of increased friction between the specimen and the guides due to increased pressure exerted as the specimen becomes thicker, it is desirable to keep the lateral restraint as small as is compatible with preventing buckling. In our fixtures the lateral restraint is far less rigid than in the authors' fixture. The 8-32 screws which we use for clamping offer comparatively little resistance to increase in thickness of the sheet yet they have provided ample lateral support to prevent buckling of sheet as thin as 0.006 in. up to stresses of 160,000 psi. and on specimens 0.020 in. thick up to stresses of 250,000 psi.

To see how much the lateral restraint

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[9] *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 665 (1944).

[10] Assistant Physicist, National Bureau of Standards, Washington, D. C.

[11] Georges Welter, "Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 683 (1944).

affected the initial modulus we made comparative tests on aluminum alloy sheet 0.128 in. thick under no lateral pressure, under our usual lateral pressure, and under pressure so high that we could not move the guide blocks with the fingers. The values obtained for the initial modulus were 10,600,000, 10,620,000 and 10,630,000 psi., respectively, showing the expected but, in our judgment, negligible increase in initial elastic modulus.

We do not understand why the authors felt it necessary to make their specimens (nominally 2 in. long) 0.10 in. or even 0.05 in. longer than the test jig. In all the curves they show, the 0.2 per cent offset yield strength was reached at strains less than 0.009 in. per inch. To determine this yield strength, which is the basis for practically all present specifications, the 2-in. specimens would need to be only 0.02 in., plus a few thousandths for end clearance, longer than the jig. We do not see why the authors could not use a specimen up to 4 in. in length with the same excess of length over the length of the jig as they have for a 2-in. specimen. This would give sufficient length for mounting an autographic gage on the specimen well away from the ends.

We have so far not found it necessary to make the specimen protrude from each end of the test jig and so have not used anything corresponding to the authors' positioning ring. In case we desired to center the guides on the specimen it could be done easily after a small load had been applied by sliding the fixture along the specimen with the fingers.

In order to minimize the effects of friction we have felt it desirable, in each assembly of a specimen in the test jig, to assure ourselves that, within reasonable limits, the initial friction is small. We adjust the clamps until the guides do not slide on the specimen under their own weight but do slide under an additional weight of 1 lb. This degree of clamping pressure has proved adequate to prevent lateral buckling.

Except in the case of some steels and magnesium alloys which yield locally it is practically always possible, after the yield stress is passed and the gages removed, to slide the test jig on the specimen with the fingers. When this is not the case we usually find evidence of some fault in our mounting technique.

We have not found it necessary to use blotting paper to obtain reasonably even loading at the two edges of a specimen. In our more rigid machines we have obtained satisfactory results by sealing, at the beginning of a series of tests, the upper bearing block to the upper head of the testing machine with a thin shim of plaster of Paris. The two bearing blocks are in contact and under a load of about 500 lb. while the plaster is setting. In machines which have appreciable lateral movement of the heads relative to each other we use a special subpress. In these machines very little improvement can be obtained by equalizing the strain at low loads.

In conclusion we wish again to congratulate the authors on their independent development of a successful testing technique and their clear presentation of their technique and experimental results.

MESSRS. HARRY LATOUR AND DON S. WOLFORD (*authors' closure by letter*).—The authors are gratified by the interest shown in their paper by those who have submitted discussions. It is believed that the remarks that follow will answer most of the questions that have been raised.

The area of the heads of the testing machines in contact with the platens was checked by means of a surface gage and found to be parallel within 0.0001 in. at the start of the tests. Only two of the 56 specimens listed in Table IV required adjustment for eccentricity by means of finger-dressing of the wet-blotting paper. The loading of specimens was considered sufficiently axial provided the initial readings of the opposite gages did not deviate from the mean value more than 10 per cent. The values shown in Table I of the discussion indicate that the initial deviations were usually less than 10 per cent, averaging 5.4 per cent for the seven specimens listed. It is evident that strains must be based on the average of readings made at both edges even when axiality is maintained within 10 per cent. The likelihood of a specimen being loaded eccentrically because of inaccuracies of specimen preparation and alignment of apparatus certainly necessitates the use of two gages if strain errors are to be minimized. Mr. Templin's adjustable bearing block appears to be a more positive method of making small adjustments than the wet-blotter method described in the paper. The wet-blotter method is not intended for correcting the nonparallel head motions of screw-type machines described by Mr. Osgood, who rightly recommends the use of a sub-press for such cases. In the authors' tests the percentage deviations between strain readings at opposite edges decreased at high stresses compared to those observed initially. See the accompanying Table I.

Messrs. Osgood and Miller discuss the possibility that the authors' jig is excessively rigid, and expressed the opinions that the Poisson effect might cause undue friction, particularly with the thicker specimens. It is recognized that the Poisson effect may lead to excessive friction between the specimen and the jig body if the latter is too rigid. However, the data in Table I show no significant increase in yield strengths with respect to thickness. Similarly, the moduli of elasticity are within usual variations except the 0.100-in. specimen which had a high value of 32,000,000 psi. It is conceivable that this high value may have been influenced by friction.

The authors constructed their jig for very large strains in excess of those required for 0.2 per cent offset strength so that compression properties could be obtained well into the plastic range. One use for compressive properties at large strains is for rationalization of the behavior of metal in plastic bending. Another important use of such data is its application to forming and drawing problems. The authors chose a compression specimen size of 0.500 by 2.000 in. which is the same as the dimensions of the gage portion of a standard rectangular tension test specimen with a 2-in. gage length. The data obtained for compression and tension should then be comparable.

TABLE I.—STRAIN DEVIATION BETWEEN OPPOSITE EDGES OF SEVEN IDENTICAL SPECIMENS OF 0.050-IN. ARMCO HIGH STRENGTH STEEL (50Y) USING HUGGENBERGER TENSOMETERS.

Specimen	Deviation in Strains Observed at Opposite Edges of Specimen, per cent	
	At Initial Load (approximately 4,000 psi.)	At Yield Strength (approximately 48,000 psi.)
No. 1	2.9	2.0
No. 2	5.2	2.8
No. 3	10.7	5.5
No. 4	5.7	0.3
No. 5	9.0	5.8
No. 6	4.4	1.2
No. 7	0.3	1.4
Average	5.4	2.7

A specimen length of 2 in. is probably the shortest that should be used in single-strip compression specimens of 0.500-in. width when a 1-in. gage length is used. The authors have seen no evidence that a longer specimen with the same 1-in. gage length would produce more accurate strain measurements. However, further study of specimen size and shape should be made before a standard size is adopted.

No comparison has been made of results obtained in the authors' jig with those obtained using recessed guides, as discussed by Mr. Townsend.

Mr. Maddon's comment regarding the possibility of excessive side pressure cannot be answered quantitatively since the application of correct thumb-screw pressure was learned by experience. The authors do not consider the 2 per cent difference in yield strength in Table I of the paper as a significant indication of excessive side pressure.

Mr. Osgood's question regarding the method of securing flatness of the internal surface against which the specimen is pressed is answered as follows:

The flat surface was machined flat from a round hole using a shaper and file before hardening and then lapped with a flat bar after hardening.

Mr. Templin raised the question as to the calibration of the gages used in modulus of elasticity measurements. The Huggenberger tensometers were calibrated prior to the authors' tests by a laboratory that specializes in servicing such instruments.

The authors regret their omission of reference to Mr. Welter's paper which gives further evidence of the merits of flat guides for supporting single-strip compression specimens. They also hope that the work of Mr. Miller and his associates will be available generally in published form in the near future.

At the time the authors initiated their first studies of flat guides for supporting single-strip compression specimens they were seeking a simple method of determining compression properties of sheet steel as processed, and were unaware of the independent works of Jackman, Welter, Miller and others. The mounting interest in the single-strip method of testing sheet materials in compression using flat guides should lead to a standardized method.

COMPRESSION TESTING OF MAGNESIUM ALLOY SHEET*

By A. A. Moore[1] and J. C. McDonald[1]

Synopsis

Methods of compression testing of magnesium alloy sheet are presented, including a rapid means of obtaining an autographic stress-strain curve. This method, which should be satisfactory for other metals, combines an adaptation of the Baldwin-Southwark Model PSH-8 extensometer with a Montgomery-Templin type jig.

Results of tests made by various methods, including "pack" and single-sheet, are given for magnesium alloys in thicknesses from 0.016 in. to 0.250 in. The use of a reduced-section specimen is recommended.

Despite the fact that the compression test is one of the oldest, good methods of performing this test on all forms of materials have not been available. The most recent developments have been in the field of sheet materials. The "pack" compression method presented by the National Bureau of Standards (**1**)[2] is satisfactory except that it is time consuming. Montgomery's single-thickness method simplified the machining and set-up. It also decreased the time required to make a test. Various means of supporting the single-sheet specimen have been used (**2**), and adaptations of autographic strainometers have speeded up the testing process (**3**).

The purpose of this paper is to discuss the factors encountered in compression testing of sheet-like specimens of magnesium alloys, and to present a rapid method of autographic stress-strain recording which is comparable in speed to that obtained under similar conditions in a tension test. The accuracy of strain recording is good, but the stress measurement includes the frictional component inherent in any means of support.

Test Methods

General:

The chief problem in sheet compression testing is to prevent buckling by using lateral support. At the same time, the frictional load must be a minimum. Any material in compression expands laterally even in the elastic range and the amount of frictional load developed depends on the supporting surface and its rigidity. The yield strength is of primary interest in compression testing, and fortunately the error introduced by friction up to this point on the stress-strain curve is small. In single-sheet testing, the specimen is left unsupported at one

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* Also published in ASTM Bulletin, No. 135, August, 1945, p. 27.

[1] The Dow Chemical Co., Midland, Mich.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 704.

end to allow sufficient compressive strain for the specimen to reach the yield strength before the platens contact the supporting jig. On very thin material this unsupported end will buckle.

Several methods of supporting the sheet specimens have been used. The pack method (1), as shown in Fig. 1, uses a pack of several pieces of the same material. The individual sheets are cemented together and supported by lateral rods.

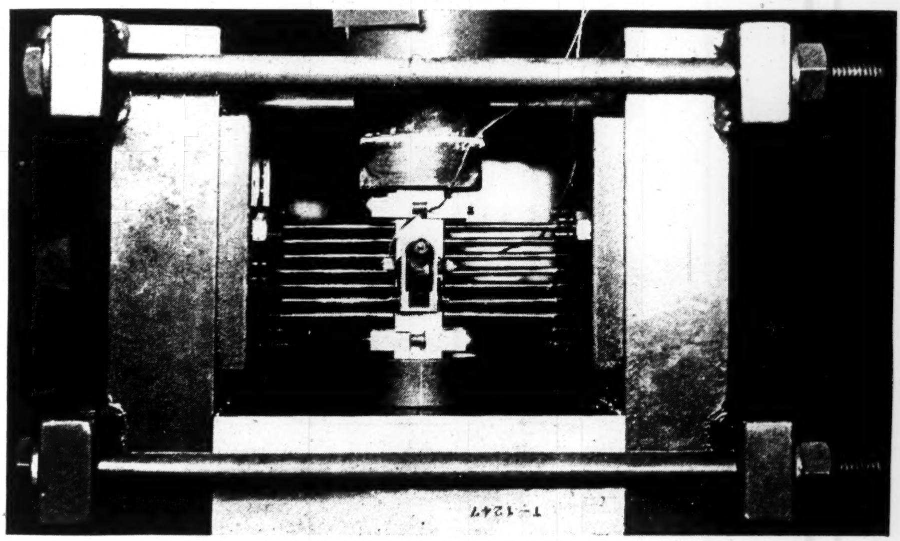

FIG. 1—Pack Compression Test with Tuckerman Gages.

Sandwich methods have been used employing smooth flat surfaces clamped to the specimen (2). For a permanent setup where the number of tests make it worth while, the Montgomery-Templin jig is preferred. For any given material, the type of support to be used should be selected after tests have been run by several methods. Flat plates are cheaper and provide support closer to the ends of the specimen than rollers. For this reason they must be used on very thin material. On some magnesium alloys it was found that rollers gave less friction and were preferable to flat polished surfaces. The probable reason for this will be discussed later.

Strainometers and Jig:

Tuckerman gages are used for precise determination of strain, with one mounted on each edge of the sheet specimen. A faster method of strain determination is desirable if the number of tests is large. Since a Templin recorder system was already in use, a setup was devised to record single-sheet compression stress-strain curves autographically (5).

Figure 2 shows the arrangement which includes a Baldwin-Southwark Model PSH-8 high-temperature extensometer with the regular adapters replaced by short rigid legs. The legs are equipped with knife-edges which are clamped against the specimen with spring pressure. The gage is held in place by a spring which allows vertical movement. Strain is measured over a 1-in. gage length in the middle of the specimen. Strain readings obtained from opposite sides of the specimen are transmitted to the extensometer, which is of the Peters averaging type. Since the jig restrains bending in all but the one plane, a close approximation of the compression strain is obtained, even if some bending is present.

To insert a new specimen, the knife-edges are pulled apart and the jig moved forward. The knife-edges are rested on the jig while the specimen is changed and then the process is reversed. The gage length is determined by the knife-edges which are locked together until after the specimen is in place. A completed compression stress-strain curve on single sheet takes about as much time as for tension.

This method was adopted to make use of the single-sheet jig which had been used with Tuckerman gages. Modulus values obtained vary about 200,000 psi. from a mean of 6,500,000 psi. This variation in modulus is less than that usually obtained in tension tests with comparable equipment. The recorder and testing machine were of the type usually used for control purposes and no special calibration factors were used. The testing machine was accurate within 0.5 per cent when calibrated with a Morehouse proving ring. The accuracy of the extensometer and recorder was checked by means of a comparator against a calibrated Tuckerman gage and was accurate within 0.0001 in. No attempt was made to control the room temperature other than the regular heating system thermostats.

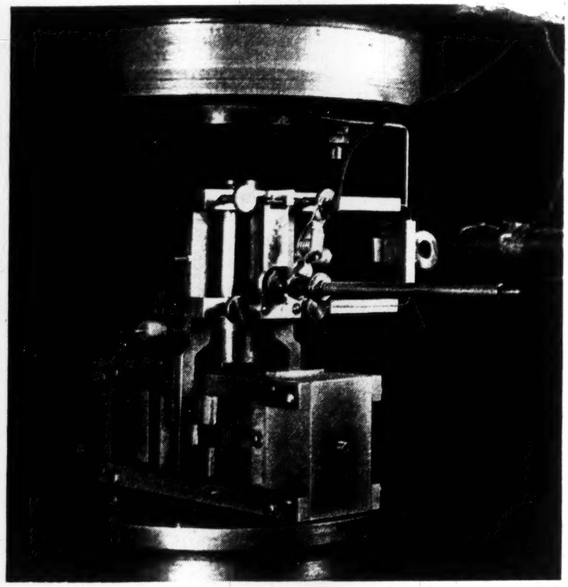

FIG. 2.—Single-Sheet Compression Test with Autographic Gage.

The jig shown is similar to the Montgomery-Templin and is 2.600 in. long. Rollers 0.095 in. in diameter were used first but were later changed for ones 0.064 in. in diameter. The flat supporting surfaces used are ground and highly polished.

Test Specimen

The regular rectangular specimen was tried first. It was found that at least 0.045 in. extra was needed on magnesium sheet alloys in addition to the jig length of 2.600 in. For the 0.064-in. diameter rollers, this left 0.077 in. of unsupported material. Buckling was encountered on some of the stronger alloys at a thickness of 0.032 in. when 0.064-in. rollers were used.

Cementing two or more thicknesses of thin sheet together to form a pack for use with the single-sheet jig did not help much in eliminating the tendency to buckle. Another method tried was to put a reduced section in the middle of the test specimen. Sheet 0.025 in. could then be tested before buckling occurred between the rollers. Other advantages for this type of specimen were discovered which will be discussed later.

Flat plate supports were tried with reduced-section specimens and material down to 0.016 in. thick was tested successfully. Tests were then run to determine how the use of the various supporting surfaces affected the test results.

Results of Tests

The various types of stress-strain curves obtained in compression of magnesium alloys have been published elsewhere (**4**). Metallurgical factors, such as orientation, determine the type of compression stress-strain curve which may be obtained. Some compression curves are similar to the tension curves but others are different. For purposes of illustration, two types of compression curves are shown in Fig. 3. One is of Dowmetal O-1HTA[3] extrusions, where the curve deviates gradually from the modulus line much as in tension. The other is of 0.064-in. thick Dowmetal FS-1a sheet which exhibits a sharp knee similar to that obtained with mild steel. In this material, Lueder's lines appear, as in steel, at the yield point. Consequently, the yield strength may be determined satisfactorily by the drop-of-beam method.

The stress-strain curves in Fig. 3 were made autographically with the apparatus shown in Fig. 2 using reduced-section specimens. It will be noticed that the strain magnification is 290 to 1. While the

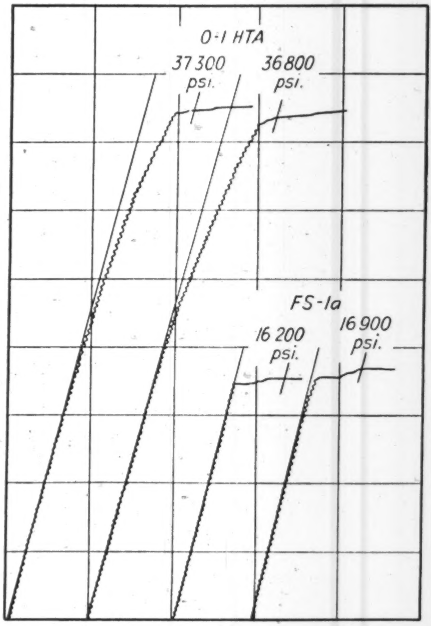

Fig. 3.—Compressive Stress-Strain Curves of Extruded Dowmetal O-1HTA and of Dowmetal FS-1aSheet.

Load—200 lb. per division.
Strain—3.45 per cent per division.
Modulus lines—6,500,000 psi.

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[3] See Table IV for compositions.

nominal magnification used is 250 to 1, the actual magnification is as given because the extensometer was used with a different recorder than the one for which it was designed. The strain is recorded by a reverse arrangement of the extensometer legs, so that the curve bears to the right, as in tension. This is done for convenience in recording.

When a rectangular specimen of FS-1a was used, the Lueder's lines were observed to start from one end of the specimen, generally the projecting end. As the test progressed, the lines proceeded toward the middle of the specimen. The specimen showed a local thickening at the Lueder's lines and wedged in the jig. All strain was absorbed locally and none was obtained from the 1-in. gage length in the middle of the specimen. This gave a considerable *wait* with neither stress nor strain being recorded. It was also found that the frictional load caused by the thickening was greater with flat plates than with roller supporting surfaces. This is shown in Table I, especially for the 0.125-in. thick annealed sheet.

TABLE I.—COMPARISON OF PACK METHOD TO PLATE SUPPORT AND ROLLER SUPPORT.

Values shown are the average of three tests.

Alloy	Gage, in.	Direction of Testing	Yield Strength, psi.		
			Flat Plate	Rollers	Pack
FS-1a................	0.125	Long.	19 200	17 700	17 800
		Trans.	19 400	17 600	17 600
	0.064	Long.	18 100	18 300	17 900
		Trans.	19 000	19 400	19 000
FS-1h................	0.125	Long.	29 400	28 400	29 200
		Trans.	29 600	29 500	29 800
	0.064	Long.	30 500	30 100	30 300
		Trans.	32 700	32 100	31 500
Ma..................	0.125	Long.	14 800	13 800	13 600
		Trans.	13 600	12 600	12 600
	0.064	Long.	12 100	12 500	12 600
		Trans.	13 100	12 900	13 100
Mh..................	0.125	Long.	18 300	18 000	17 800
		Trans.	17 100	16 800	17 400
	0.064	Long.	20 000	19 400	19 500
		Trans.	18 200	17 900	17 900

Lueder's lines are found after compression on cold-rolled sheet and on extruded material. The

TABLE II.—COMPARISON OF VARIOUS SUPPORTS TO NO SUPPORT.

Values shown are the average of two tests.

Alloy	Gage, in.	Direction of Testing	Yield Strength, psi.			
			Roller Supports			
			Plain Bar	Reduced-Section Bar	Pack	Specimen 2 in. Long No Support
FS-1a...........	0.250	Long.	15 400	15 300	15 600	14 600
		Trans.	16 300	15 900	15 900	15 000
FS-1h...........	0.250	Long.	27 600	27 800	27 900	26 900
		Trans.	31 200	31 300	31 300	30 300
J-1a............	0.250	Long.	15 100	15 100	14 700	14 600
		Trans.	15 700	15 900	15 500	15 400
J-1h............	0.250	Long.	25 100	25 500	26 300	24 800
		Trans.	29 300	29 700	30 300	28 500
Ma..............	0.250	Long.	11 800	11 500	11 600	11 100
		Trans.	10 900	10 900	10 900	9 900
FS-1a...........	0.032	Long.	17 700	17 100	17 600	....
		Trans.	20 100	18 600	18 200	....
FS-1h...........	0.032	Long.	31 400	31 800	[a]	....
		Trans.	32 800	33 200	[a]	....

[a] Buckled below yield strength.

effect is less pronounced on the stronger material with less local thickening. The results of tests were about the same on cold-rolled sheet regardless of whether roller or flat plate supports were used.

The use of a reduced section $1\frac{1}{4}$ in. long with an area about 15 per cent less than the ends eliminated the Lueder's lines, except in the reduced section, and decreased the frictional load in some cases, as will be seen from Table II. Alloy FS-1a gave much lower values when a reduced section was used. With all of the plastic strain taking place in the reduced section the specimen length was changed to 2.630 in. The standard specimen in use at the present time is shown in Fig. 4.

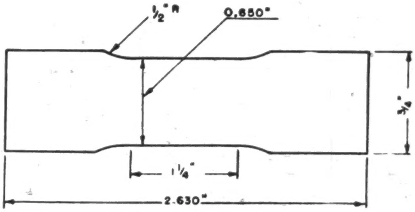

FIG. 4.—Reduced-Section Specimen.

It is recognized that any form of support will give a higher value. This is shown by Table II where specimens from $\frac{1}{4}$-in. plate were tested as a single sheet with roller supports, as a pack, and unsupported. The unsupported specimens were 2 in. long and $\frac{3}{4}$ in. wide. The strain was measured over a 1-in. gage length in the middle. The average of all tests on $\frac{1}{4}$-in. plate shows the unsupported specimens to have a yield strength 4.4 per cent lower than the average of the values obtained with reduced-section specimens supported by roller surfaces. Individual values ranged from 3.2 to 9.0 per cent lower but part of this may be due to material variation.

Sheets 0.125 in. and 0.064 in. thick were tested for a comparison of single-sheet results with the pack method. Good agreement was obtained between the pack and single-sheet methods; especially if rollers were used. The pack specimens buckled below the yield strength when 0.032-in. Dowmetal FS-1h sheet was tested.

TABLE III.—COMPARISON OF ROLLER SUPPORT TO PLATE SUPPORT FOR 0.016-IN. SHEET SPECIMENS WITH REDUCED SECTIONS.

Values shown are the average of two tests.

Alloy	Gage, in.	Direction of Testing	Yield Strength, psi.	
			Flat Plate	Rollers
FS-1a...	0.016	Long.	18 300	18 200[a]
		Trans.	18 600	18 000[a]
FS-1h...	0.016	Long.	29 600	29 000[a]
		Trans.	30 700	29 000[a]

[a] Buckled.

Table III shows the results of tests on 0.016-in. FS-1a and FS-1h sheet. Reduced-section specimens were used. None of those tested with flat plates buckled, while those tested with roller supports did. In all cases the yield strength was apparently reached before buckling as shown by comparison with the results from the tests made with flat plate supports. Buckling is always undesirable because it is never known whether it occurred below the yield strength or not.

From the tables presented, it will be noted that the annealed sheet (designated by the letter *a*) was more sensitive to test methods than the cold-rolled or stronger alloys (designated by the letter *h*) which are generally used in stressed applications. This also applies to single-sheet specimens machined from extrusions, such as angles, channels, and tees, that is, stronger alloys are less sensitive than the weaker alloys.

SUMMARY

1. On commercial Dowmetal sheet alloys the regular pack method with supporting rods ¼ in. apart could be used for 0.064-in. sheet. The 0.032-in. sheet buckled.

2. Accurate compression stress-strain curves may be obtained in single-sheet tests by use of regular autographic equipment with a suitable jig.

3. In single-sheet specimens the following limiting minimum thicknesses were found:

(*a*) Flat plate supports, reduced section specimen—less than 0.016 in.

(*b*) 0.064-in. diameter roller supports, rectangular specimen—0.032 in.

(*c*) 0.064-in. diameter roller supports, reduced section specimen—0.025 in.

4. Some magnesium sheet alloys exhibit a sharp-kneed compressive stress-strain curve accompanied by pronounced Lueder's lines similar to tension on mild steel.

5. The use of a reduced-section single-sheet specimen is recommended for some alloys and conditions.

TABLE IV.—NOMINAL CHEMICAL COMPOSITION OF MAGNESIUM-BASE ALLOYS TESTED, PER CENT.

Alloy	Aluminum	Manganese, min.	Zinc	Iron, max.	Nickel, max.
Dowmetal FS-1	3.0	0.2	1.0	0.005	0.005
Dowmetal J-1	6.5	0.15	0.9	0.005	0.005
Dowmetal M	...	1.2	...	...	...
Dowmetal O-1	8.5	0.15	0.5	0.005	0.005

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(2) K. R. Jackman, "Improved Methods for Determining the Compression Properties of Sheet Metal," *Automotive and Aviation Industries*, Vol. 90, No. 11, pp. 36–38, 82 (1944).

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(5) R. L. Templin, "An Automatic Autographic Extensometer for Use in Tension Tests of Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part II, p. 783 (1932).

CAST-TO-SIZE IMPACT SPECIMENS FOR ALUMINUM SAND CASTING ALLOYS*

By R. A. Quadt[1]

The usual procedure for obtaining specimens for impact testing of metals cast in sand involves the machining of the finished specimen from an oversize cast-to-shape test specimen, or the machining of a specimen from a section of a production casting. This is an expensive and time-consuming operation which mitigates against common use of the test except in certain required instances.

The author has been concerned with the development of a body of data relating to the properties of sand-cast aluminum alloys, and in this work it has been desirable to include impact values. The chief deterrent to such a program is the expense and time delay referred to above. Hence it was decided to investigate the possibility of producing cast-to-size impact test specimens in green sand which would satisfy the following criteria:

1. Multiple test specimens from one casting were desired so that a number of specimens would be available for duplicate tests.
2. The test specimens from a single casting should produce reasonably consistent impact values.
3. Test specimens from different castings produced under similar conditions should give comparable results.

It could not be predicted how the impact values obtained would compare with those found on specimens machined as in standard practice, hence machined test specimens were utilized for comparison purposes throughout the investigation.

Method and Data

The type of specimen investigated was the 10 by 10 by 55-mm. Charpy test specimen. Wherever a notch was provided, it was the V type conforming to A.S.T.M. specifications.[2] A wood matchboard similar to the casting shown in Fig. 1 was designed for the initial tests except that no notches were provided in the pattern and specimens were placed closer together. A commercial aluminum 4 per cent copper alloy of the following composition was used for all work in the investigation:

ALLOY F410

Copper, per cent	4.70	Nickel, per cent	0.02
Silicon, per cent	1.18	Manganese, per cent	0.37
Magnesium, per cent	0.05	Titanium, per cent	0.1
Zinc, per cent	0.25	Chromium, per cent	0.005
Iron, per cent	0.74	Aluminum, per cent	Balance

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* Also published in ASTM Bulletin, No. 135, August, 1945, p. 24.

[1] Central Research Laboratory, American Smelting and Refining Co., Barber, N. J.

[2] Tentative Methods of Impact Testing of Metallic Materials (E 23 - 41 T), 1944 Book of A.S.T.M. Standards, Part I, p. 1962.

It was melted in a No. 45 clay graphite crucible in a coke-fired, forced draft pit furnace. The crucible was removed when the metal reached a temperature of about 1450 F. A series of castings was poured in green sand molds produced from the matchboard. To determine the optimum pouring temperature for the pattern design, a pair of castings was poured at 1400 F., 1300 F., and at 1220 F. They were shaken out in 15 to 30 min.

It was immediately apparent from this preliminary test that the pattern design was faulty in that the specimens were too close together. The matchboard could not be drawn without disturbing the sand between the specimens; hence this first group of castings contained several specimens which were too rough and misshapen to be used. The remaining specimens were tested in the as-cast and heat-treated tempers and indicated, as expected, that the pouring temperature of 1220 F. gave the highest average values and the lowest spread. This is attributed at least in part to the fact that the smallest grain size (0.5 mm.) resulted from the low pouring temperature.

In order to standardize the testing operation, the parting line surface was always placed parallel to the striking surface on the side away from the hammer. It is the surface, therefore, which sustains the greatest stress. Although both the cope and drag positions were reversed for several tests with no significant difference in the impact resistance, the cope surface was chosen for this purpose since it consistently presented the smoothest surface, and it was hoped that notch effects could be minimized.

Specimens were tested at room temperature on a Baldwin-Southwark modified Charpy impact machine of 16 ft-lb. capacity. The machine design has been adequately described elsewhere.[3] Each scale division represents 0.08 ft-lb. The cast-to-size unnotched specimens in the solution-heat-treated condition exceeded the breaking range of this machine; therefore they were broken in a Riehle 110 ft-lb. capacity machine on which the scale is subdivided into 1 ft-lb. increments and values can be estimated to 0.5 ft-lb. Tup velocity was 12.0 ft. per sec. for both machines.

As a result of these exploratory tests, the pattern was revised to the extent that the test specimens were respaced $\frac{5}{8}$ in. apart and contained 26 unnotched specimens. Only about 0.005-in. draft was accorded the test specimens to approximate the desired square section as closely as possible. The alloy was then remelted and a group of castings poured at 1220 F. Specimens were numbered 1 to 26 on each casting starting at the top-right corner opposite the sprue and numbering clockwise. The specimens of two castings were tested in the as-cast condition four days after they were produced. Another set was tested in the solution-heat-treated condition and a fourth and fifth set tested after various aging treatments. Specimens from these last two castings were selected at random since it was desired to duplicate normal procedure. Solution heat treatments were conducted at 960 F. for 15 hr. in an electrically heated, circulating air furnace, quenching in boiling water. Solution-treated specimens were aged 24 hr. at room temperature before being tested or artificially aged. Aging at 310 F. was accomplished in constant temperature, electrically heated salt baths. The results are summarized in Table I. No significant effect due to position in the casting could be determined from the individual results.

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[3] R. Burns and W. W. Werring, "The Impact Testing of Plastics," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 40 (1938).

TABLE I.—IMPACT STRENGTH OF CAST-TO-SIZE UNNOTCHED SPECIMENS.

Heat Treatment	Number of Specimens	High (ft-lb.)	Low (ft-lb.)	Mean (ft-lb.)
As cast				
First casting	25	10.4	7.3	8.4
Second casting	21	9.2	7.4	8.2
Solution heat treated	31	21.0	15.5	18.5
Solution heat treated and aged 3 hr. at 310 F.	14	15.4	11.9	13.4
Solution heat treated and aged 6 hr. at 310 F.	13	13.7	10.5	12.3
olution heat treated and aged 24 hr. at 10 F.	13	9.3	5.5	7.3

TABLE II.—IMPACT STRENGTH, FT-LB.

Heat Treatment	Machined and Unnotched	Machined and V Notched	Cast to Size with Machined V Notch
As cast	4.0	1.4, 1.3	1.8, 1.8, 2.0
Solution heat treated	11.0, 9.7	4.1, 4.7	5.2, 5.7, 5.4
Solution heat treated and aged 3 hr. at 310 F.	7.6	3.0, 3.2	3.0, 3.4, 3.2
Solution heat treated and aged 6 hr. at 310 F.	4.7	2.2, 2.5	2.6, 2.4, 2.8
Solution heat treated and aged 24 hr. at 310 F.	2.7	1.3, 1.4	1.5, 1.5, 2.0

To obtain comparable values on standard machined and notched specimens, ten test specimens were cut from the bottom of the outside runners where the feeding and freezing characteristics most closely approximated those of the cast-to-size specimens. Grain size determinations averaged 0.7 mm. on the specimens obtained from the runners. Six more specimens were cut from similar locations in other castings and milled 10 mm. square but left unnotched. Finally, notches were machined into fifteen of the cast-to-size bars. All were heat treated and tested as previously described. The impact results are listed in Table II.

It was decided to attempt to cast the V notch into the specimens directly so a second alteration to the matchboard was made. One half of the specimens had specification V notches cut into the drag surfaces. The casting produced is shown in Fig. 1. The alloy was again re-

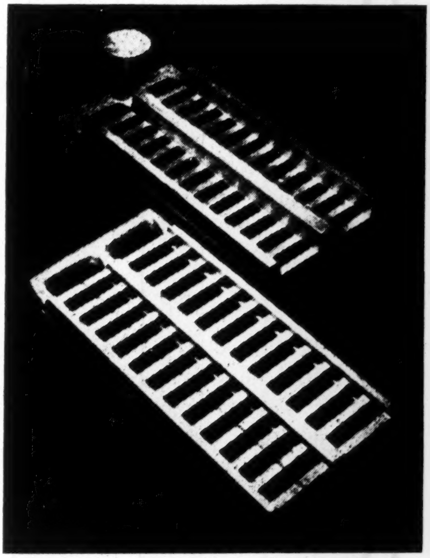

FIG. 1.—Aluminum Sand Castings for Producing 26 Cast-to-size 10 by 10-mm. Charpy Impact Specimens.

Top: Cope view; *Bottom:* Drag view.

melted and cast at 1220 F. The notched bars from one of the castings were tested about 6 hr. after pouring. The notched bars from other castings were heat treated and tested as before. The results are tabulated in Table III.

TABLE III.—IMPACT STRENGTH OF CAST-TO-SIZE BARS WITH V NOTCH CAST INTO SPECIMEN.

Heat Treatment	Number of Specimens	High (ft-lb.)	Low (ft-lb.)	Mean (ft-lb.)
As cast	13	2.5	1.8	2.1
Solution heat treated	9	5.4	4.1	2.7
Solution heat treated and aged 3 hr. at 310 F.	7	3.0	2.4	4.6
Solution heat treated and aged 6 hr. at 310 F.	7	2.1	1.8	2.0
Solution heat treated and aged 24 hr. at 310 F.	7	1.4	1.2	1.4

The effect of room temperature aging on the as-cast impact properties of this alloy was investigated when it was noted that specimens from the same castings did not check specimens tested at an earlier date. The results are tabulated in Table IV.

These data indicate that the "as-cast" values given for the various types of specimens are not strictly comparable since those specimens requiring machining were obviously aged somewhat in the interim between casting and testing. All machined specimens were tested within a week of casting, however, so the discrepancy due to the aging factor is not too great.

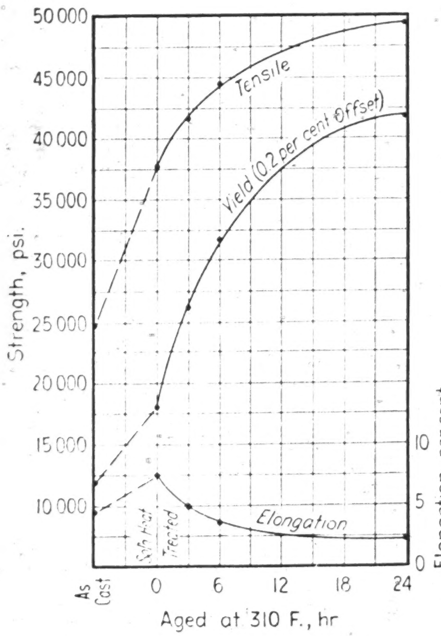

FIG. 2—Tensile Properties of the Aluminum Alloy Investigated.

DISCUSSION

Tension test data were obtained on this alloy from standard cast-to-size ½-in. test bars poured at 1220 F. into green sand molds. Properties obtained from these bars are plotted in Fig. 2. Three to five bars were used for each treatment. Impact data from Tables I, II, and III are summarized in Fig. 3. In order that a constant cross-section area

TABLE IV.—EFFECT OF ROOM TEMPERATURE AGING ON IMPACT RESISTANCE IN AS-CAST CONDITION.

Aging Period, days	Unnotched				Notched			
	Number of Tests	High (ft-lb.)	Low (ft-lb.)	Mean (ft-lb.)	Number of Tests	High (ft-lb.)	Low (ft-lb.)	Mean (ft-lb.)
1	12	11.1	8.0	9.8	13	2.5	1.8	2.1
4	46	10.4	7.3	8.3	...	...	...	...
18	7	7.2	5.2	6.2	4	1.3	1.1	1.2
35	4	5.4	4.2	5.0	...	...	...	...

might be utilized in comparing the results of the various tests, values were recalculated where necessary to a standard cross-section area of 80 sq. mm. The cast-to-size unnotched specimens approximated 10.5 mm. square due to the vibration required in drawing the pattern. The notches cut in the pattern had the correct angle and root radius but were about ½ mm. too deep. The dimensions of a particular type of cast specimen, however, checked closely from specimen to specimen, varying but a few thousandths of an inch.

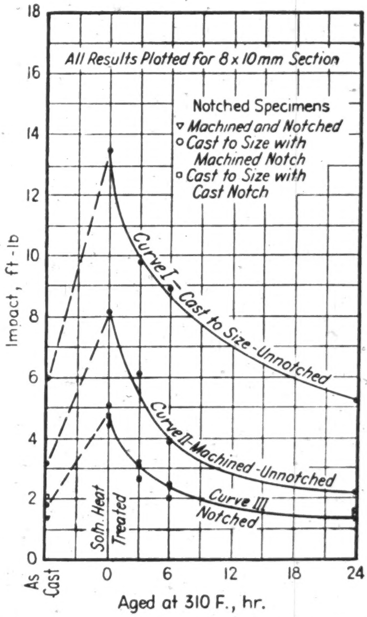

FIG. 3—Impact Strength of Various Types of Specimens with Constant Cross-Section.

Several interesting observations may be made from the impact curves. Due to the similarity of the three curves in Fig. 3, these remarks apply to any of the tempers investigated. The first concerns the effect of the casting skin on unnotched bars. Except for slight differences in freezing rate in the specimens used to produce curves I and II, the difference in toughness must be attributed to the casting skin. Roughly 50 per cent of the impact resistance of cast-to-size unnotched specimens for this alloy is due to the superior toughness of this outer skin. This skin effect is no longer apparent, however, upon casting a standard V notch into the specimen. The notch completely dominates the test and renders ineffective the superior toughness of the casting skin. Differences among the three types of specimens used to develop curve III are not significant.

Secondly, the notch sensitivity of the alloy is indicated by the difference between curves I and III, and between curves II and III. Stress concentrations due to the notch reduce the toughness of a cast-to-size specimen by approximately two thirds. Machined specimens lose about one half their initial impact strength. The actual energy absorbed in fracturing each type of specimen is essentially the same; hence a notched machined specimen and a notched cast-to-size specimen have the same impact strength.

CONCLUSIONS

The results of this investigation indicate that it is possible to produce quickly and cheaply cast-to-size Charpy impact specimens which satisfy the criteria outlined in the introduction of this paper. Both notched and unnotched test specimens may be obtained from a single sand casting. It is thus possible to obtain data on two sometimes unrelated properties of an alloy: its impact resistance and its sensitivity to notching.[4] This method of producing impact specimens has been incorporated into a research program with very satisfactory results. Several thousand specimens have been cast and tested to date on most of the common aluminum casting alloys. Generally, several impact castings are poured along with the usual tension test bars from a single heat of metal.

For the aluminum alloy reported here, the values obtained from cast-to-size notched specimens closely check those obtained from bars machined and notched from a comparable oversize casting. Unnotched cast-to-size specimens, however, have approximately double the impact values obtained from unnotched machined specimens.

Acknowledgment:

The work reported in this paper is part of a program of research conducted at the Central Research Laboratory of the American Smelting and Refining Co. for the Federated Metals Division.

The guidance and interest of A. A. Smith, Jr., is gratefully acknowledged. Miss Doris Marshall assisted in carrying out the laboratory work.

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[4] S. L. Hoyt, "Notched-Bar Testing and Impact Testing," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 141 (1938).

ELECTRICAL CONDUCTIVITY OF CONDUCTORS*

By L. F. Roehmann[1]

Synopsis

The multiplicity of terms and units employed to designate the electrical resistivity and conductivity of conductors has led to inconsistency and confusion. Specifically, the creation and codification of mass resistivity and mass conductivity, on a par with volume resistivity and volume conductivity, seem unnecessary and confusing. It is therefore suggested, in dealing with electrical conductors, to retain but one quantity, and to use it universally. For this quantity, per cent volume conductivity is suggested. The reasons for this choice are given.

With present-day measuring technique, per cent volume conductivity can always be determined with a sufficiently high degree of accuracy, even if area has to be determined indirectly from length, weight, and density. The validity of this statement is supported by test data on fine copper wire, No. 36 A.w.g. (0.005 in. in diameter), bare *versus* tinned *versus* lead-alloy coated.

The following recommendations are put forward:

1. Uniformly standardize conductivity of electrical conductors on the basis of per cent volume conductivity.
2. Adopt the coil form method outlined in this paper as a tentative standard for the determination of per cent volume conductivity of fine wire.
3. Enlarge the scope of A.S.T.M. Tentative Method of Test for Density of Fine Wire and Ribbon for Electronic Devices (B 180–43 T),[2] by the inclusion of other than heavy test liquids.

An electrical conductor, within the scope of this paper, is defined as a metallic wire, cable, rod, bar, strip, tube, or profile which is longitudinally invariant. This means that the cross-sectional area is constant, and, in addition, that the cross-sectional metal distribution does not change if the conductor is made of different metals. Examples are Copperweld wire (steel core with copper sheath) and fine copper wire with tin or lead-alloy coating.

Volume and Weight Resistivity

The interrelation between resistance R, length l, and area A of an electrical conductor is expressed by the well-known equation

$$R = \rho \frac{l}{A} \quad \ldots\ldots\ldots\ldots (1)$$

where the proportionality factor ρ is termed the resistivity or, more accurately, volume resistivity. The resistance R is the quantity which enters directly into voltage and cur-

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* Also published in ASTM Bulletin, No. 134, May, 1945, p. 58.

[1] Research Engineer, Electrical Lab., Anaconda Wire and Cable Co., Hastings-on-Hudson, N. Y.

[2] 1944 Book of A.S.T.M. Standards, Part I, p. 1803.

rent calculations of a specific circuit. It depends upon the length of the conductor and its cross-sectional area. The volume resistivity ρ is not dependent upon length and area. It is a more fundamental quantity, and usually associated with the material of which the conductor is made.

Resistance is universally expressed in ohms. Conductor length, however, is expressed in centimeters, meters, kilometers, feet, or miles. Conductor cross-sectional area is expressed in square millimeters, square centimeters, square inches, or circular mils. It follows that the fundamental quantity, resistivity, is expressed in a multiplicity of ways, and obscured by numerous conversion factors. The same is true of volume conductivity, the reciprocal of volume resistivity, which is used by some authors in lieu of volume resistivity.

The foregoing represents but a part of the story. As an alternate to Eq. 1, and on a par with it, the following relation holds between resistance R, length l, and weight W of a conductor:

$$R = \delta \frac{l^2}{W} \ldots\ldots\ldots\ldots (2)$$

According to this equation, the resistance is proportional to the square of the length, inversely proportional to the weight, and proportional to the "weight resistivity" δ. The latter is frequently misnamed "mass resistivity." The resistance is expressed in ohms; conductor length in centimeters, meters, kilometers, feet, or miles. The conductor weight is expressed in grams, kilograms, or pounds. Hence there exists a second set of resistivities, namely, "weight resistivities" and their reciprocals, "weight conductivities."

PER CENT CONDUCTIVITY

To complete the story, conductivity of a conductor, or conductor material, is customarily expressed not as an absolute quantity but as a relative quantity, namely as a percentage of a standardized conductivity. The International Electrotechnical Commission in 1913 adopted a resistivity value known as the International Annealed Copper Standard (IACS). The normal values for standard annealed copper were established as follows:[3]

> "1. At a temperature of 20 C. the resistance of a wire of standard annealed copper 1 meter in length and of a uniform section of 1 sq. mm. is $^1/_{58}$ ohm = 0.017241 . . . ohm.
>
> "2. At a temperature of 20 C. the density of standard annealed copper is 8.89 g. per cu. cm.
>
> "3. . . . . . .
>
> "4. As a consequence, it follows from (1) and (2) that at a temperature of 20 C. the resistance of a wire of standard annealed copper of uniform section 1 meter in length and weighing 1 g. is $(^1/_{58}) \times 8.89$ = 0.15328 . . . ohm."

From the foregoing definitions, two resistivities for standard annealed copper at 20 C. are obtained:

Volume resistivity

$$\rho_s = 0.017241 \frac{\text{ohm sq. mm.}}{\text{meter}}$$

$$= 1.7241 \frac{\text{microhm sq. cm.}}{\text{cm.}}$$

or michrom-cm.

Weight resistivity

$$\delta_s = 0.15328 \frac{\text{ohm}}{\text{meter}} \times \frac{\text{gram}}{\text{meter}}$$

$$= 875.20 \frac{\text{ohm}}{\text{mile}} \times \frac{\text{pounds}}{\text{mile}}$$

Since Eqs. 1 and 2 express the volume resistivity and weight resistivity, respectively, of any electrical conductor, it follows that there are two values of per cent conductivity for any conductor:

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[3] Circular No. 31 of the National Bureau of Standards.

1. *Volume* per cent conductivity

$$c = 100 \frac{\rho_s}{\rho}$$

$$= 100 \times \frac{0.017241}{\rho} \text{ (basis: ohm, sq. mm., meter)}$$

$$= 10^{-4} \times \frac{1.7241}{\rho} \text{ (basis: ohm, cm.)}$$

2. *Weight* per cent conductivity

$$c_w = 100 \frac{\delta_s}{\delta}$$

$$= 100 \times \frac{0.15328}{\delta} \text{ (basis: ohm, meter, gram)}$$

$$= 100 \times \frac{875.20}{\delta} \text{ (basis: ohm, mile, pound)}$$

TABLE I.—RESISTIVITY AND CONDUCTIVITY AS GIVEN IN VARIOUS A.S.T.M. SPECIFICATIONS FOR ELECTRICAL CONDUCTORS.

A.S.T.M. Designation[a]	Title	Quantity	Basis	Unit
B 187–44 T.	Tentative Specifications for Copper Bus Bars, Rods and Shapes	Resistivity Conductivity	Weight	Ohms (meter, gram) Per cent
B 1–40.....	Standard Specifications for Hard-Drawn Copper Wire	Resistivity	Weight	Ohms (mile, pound)
B 105–39...	Standard Specifications for Hard-Drawn Copper Alloy Wires for Electrical Conductors	Resistivity	Weight Volume	Ohms (mile, pound) Ohms (mil, foot)
A 111–43...	Standard Specifications for Zinc-Coated (Galvanized) Iron or Steel Telephone and Telegraph Line Wire	Resistivity	Weight	Ohms (mile, pound)
B 82–41....	Standard Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium for Electrical-Heating Elements	Resistivity	Volume	Ohms per circular mil foot Ohms per square mil foot Microhms per centimeter cube
B 82–44 T..	Tentative Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium for Electrical-Heating Elements	Resistivity	Volume	Ohms per circular mil foot Ohms per square mil foot Microhms per centimeter cube
B 118–42 T.	Tentative Methods of Testing Nickel and Nickel-Alloy Wire and Ribbon for Electronic Tube Filaments	Resistivity	Volume Weight	Ohms per circular mil foot, microhm - centimeters, or ohm-milligram per 200 millimeter-feet

[a] 1944 Book of A.S.T.M. Standards, Part I.

Volume per cent conductivity and weight per cent conductivity are numerically equal only if the conductor density at 20 C. is 8.89, that is, if the conductor is made of copper. For other values of density, the two conductivities are numerically different.

To recapitulate, the electrical resistivity, or conductivity of an electrical conductor can be designated by the following quantities:

Volume resistivity or Volume conductivity	Expressed in numerous ways, depending upon the units used for measuring length and area.
Weight resistivity or Weight conductivity	Expressed in numerous ways, depending upon the units used for measuring length and weight.
Per cent volume conductivity or Per cent weight conductivity	Expressed in per cent of IACS.

The complications which ensue from this multiplicity of terms, definitions, and units are well reflected in Table I. This is a compilation prepared from A.S.T.M. specifications pertaining to electrical conductors, and shows the wide range of expressions included for representing a single concept.

Suggested Simplification:

The need for simplification, unification, and correction is apparent. It is, therefore, suggested, in dealing with the conductivity of electrical conductors, to eliminate all quantities except one, and to use this one quantity for all conductors regardless of size, metal, or metal composition, and specific application. Per cent volume conductivity is suggested.

Per cent is suggested because this dimensionless unit is universally understandable. The reference value is 100 per cent, IACS, although it is recognized that this standard is no absolute quantity in a physical sense. Commercial copper is available today with per cent conductivities above or below 100 per cent IACS.

Volume conductivity is suggested for several reasons. First, this quantity is used exclusively, though maybe unknowingly, in verbal discussions. One speaks of an aluminum conductor of some 60 per cent conductivity, but not of one having some 200 per cent (the latter would be per cent weight conductivity). Second, commercial conductors, such as Copperweld, Copperweld-Copper composite, aluminum cables-steel reinforced (ACSR), or bronze, are customarily listed with actual and "equivalent copper" cross-sectional areas.[4] The volume concept is again apparent. The ratio of equivalent copper cross-section to actual cross-section is one one-hundredth of the per cent volume conductivity.

When an engineer deals with electrical conductors, he prefers, quite generally, the volume to the weight concept. Whether it is the current density, depth of penetration or even conductor resistance, it is the volume or area, not the weight concept, which he actually applies. No textbook on circuit theory or energy transmission considers weight. Field equations are a matter of potentials and geometry but not of weight. But when resistivity and conductivity are considered, both volume and weight concept are legalized, and when wire, particularly fine wire is the object, the weight concept is considered superior.

Basis for Acceptance of Weight Concept:

An important reason for the acceptance of the weight concept and its subsequent codification in many A.S.T.M. standards may have been the arguments set forth in Bureau of Standards Circular No. 31.[3] The following statements are quoted from it (page 63):

> "The reasons why the mass resistivity is preferable to the volume resistivity may be summarized as follows:
>
> "1. The measurement of either cross-section or density in many cases is difficult and inaccurate.
>
> "2. The direct measurement of cross-section is practically impossible for irregular shapes of cross-section.
>
> "3. Conductors are sold by weight rather than by volume, and therefore the information of value to most users is given directly by the mass resistivity."

During the interval of more than thirty years since the publication of Circular No. 31, the conclusion reached in the last reason, that "the information of value to most users is given directly by the mass resistivity," has proved to be incorrect. The designer of a Copperweld transmission line, or the purchaser of a high-strength low-conductivity bronze trolley wire, is interested in the equivalent copper cross-section of the material under consideration. It is the volume, not the weight concept which predominates.

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[4] *Electrical Transmission and Distribution Reference Book,* Westinghouse Electric and Manufacturing Co., 1942, pp. 32 and 34; and similar reference books.

The second reason is, of course, correct but predicated upon the first. If an easy and sufficiently accurate method for indirect area determination is available, both arguments lose their foundation.

Recent Standards:

Reasoning along these lines probably led to the adoption of A.S.T.M. Standard Method of Test for Resistivity of Metallic Materials (B 63 - 36).[5] This standard sets forth a method for *volume* resistivity determination with an accuracy of 1 per cent. Referring to cross-sectional area measurements, the standard specifies micrometer measurements on wire specimens or strips, if and when the mean cross-section can be obtained within 0.5 per cent. Section 5(*a*) reads in part,

> "In case the diameter of the wire or the thickness of the strip cannot be measured to give the above accuracy with the micrometer available, the cross-section shall be determined from the weight, density, and length of the specimen."

The standard proceeds to describe density measurements in water, and to point out the necessary precautions to insure accuracy.

A.S.T.M. Tentative Method of Test for Density of Fine Wire and Ribbon for Electronic Devices (B 180 - 43 T)[2] shows the way for an improvement in accuracy for specimens of low weight. If water, with a density of 1 g. per ml. is replaced by a heavy liquid, such as tetrabrom-acetylene with a density of nearly 3, the accuracy in density determination is increased about threefold. The scope of A.S.T.M. Method B 180 provides a test method for density determination of fine wire, 0.001 to 0.010 in. in diameter, and of ribbons of similar thickness, for electronic devices, with an accuracy of 0.1 per cent. To accomplish this objective, an exacting laboratory technique is required, and the detailed procedure is set forth in the standard.

When our chemical laboratory recently undertook to determine the densities of No. 36 A.w.g. copper wire, bare, tinned, and lead-alloy coated, by following the provisions of A.S.T.M. Method B 180, difficulties were encountered. The data were erratic and not reproducible. Failure was attributed to the testing liquid tetrabrom-acetylene. Its poor wetting characteristic makes it well nigh impossible to remove all traces of air clinging to the wire, even when it is boiled under vacuum. Furthermore, the lead-alloy coated wire was corroded by the liquid.

Success was achieved by substituting isopropyl ether. This liquid is chemically inert, wets easily, boils *in vacuo* at room temperature, and has a low temperature coefficient. These advantages outweigh, in our opinion, the disadvantage of low density (0.7427 g. per ml.). Additional work on this subject is underway. It seems advisable to enlarge the scope of Method B 180 beyond fine wire and ribbon for electronic devices, and to amend the standard according to these findings.

Once density of the specimen is determined, the remaining three quantities necessary for per cent volume conductivity determinations, namely, resistance, length, and weight, are obtained quite easily.

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[5] 1944 Book of A.S.T.M. Standards, Part I, p. 890.

ANACONDA COIL FORM METHOD

The Anaconda Laboratories have developed a method for tests on fine wire which is convenient and sufficiently accurate for engineering purposes. Its main feature is the use of a cylindrical coil form having a helical groove (Corning Pyrex Glass Multiform Coil Form) on which the specimen is wound. The wire specimen is soldered to rectangular copper lugs which are brazed to substantial binding posts. The assembly is inserted into a chamber with controlled heat and refrigeration to attain reference temperature. The resistance of the wire specimen is measured with an accurate Wheatstone bridge connected to the specimen by short, heavy leads. The wire is then cut off at the lugs, removed from the coil form and weighed.

Two coil forms are used. The smaller form is 3½ in. long and has an over-all diameter of 2 in. It is used for wire sizes No. 28 to 36 A.w.g. and accommodates about 16 ft. The larger form is 5¾ in. long and has an over-all diameter of 2¾ in. It is used for wire sizes No. 22 to 27 A.w.g. and No. 37 to 44 A.w.g. and accommodates about 60 ft.

The resistance of wire sizes No. 21 A.w.g. and larger may be measured with a Kelvin bridge on straight specimens without resorting to the coil-form method.

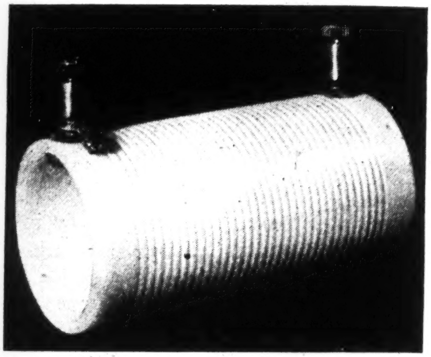

FIG. 1.—Small Coil Form with No. 36 A.w.g. Wire.

Figure 1 shows the small coil form with No. 36 A.w.g. wire wound upon it.

The following considerations governed the development of the coil-form method and the assignment of wire sizes and lengths applicable to each form:

TABLE II.—PER CENT VOLUME CONDUCTIVITY. NO. 36 A.W.G. COPPER WIRE, BARE, LEAD-ALLOY COATED, AND TINNED.

Specimen	Resistance, R_{20}, ohms	Length, l, cm.	Weight, W, g.	Density, D, g. per cu. cm.	Diameter, d, mils	Volume Conductivity c, per cent
			SPOOL I			
Bare copper wire	6.870	515.3	0.5967	8.90	5.07	99.4
	6.901	515.3	0.5937	8.90	5.05	99.5
	6.860	515.3	0.5972	8.90	5.07	99.5
Same wire, lead-alloy coated	6.867	515.3	0.6341	8.97	5.20	94.3
	6.870	515.3	0.6241	8.97	5.16	95.8
			SPOOL II			
Bare copper wire	6.874	515.3	0.5896	8.90	5.04	100.6
	6.881	515.3	0.5900	8.90	5.04	100.4
Same wire, tinned	7.032	515.3	0.5872	8.89	5.03	98.6
	7.030	515.3	0.5872	8.89	5.03	98.6
Same wire, tin removed	7.176	515.3	0.5653	8.90	4.93	100.5
	7.205	515.3	0.5630	8.90	4.92	100.5

1. The resistance of the specimen should exceed one ohm, the lower limit for Wheatstone bridge measurements.
2. The specimen weight should exceed 0.5 g., the lower limit for accurate weighing.
3. Soldering of the wire specimens to the copper lugs eliminates difficulties due to contact resistance.
4. Dimensional stability of the coil form obviates the need for individual length measurements. The lengths between lug tips have been established for every wire size tested.
5. Compactness of the coil permits of its insertion into a small chamber and assures uniform temperature.

Application of Method:

Table II shows the results obtained in the determination of per cent volume conductivity on No. 36 A.w.g. copper wire, bare, lead-alloy coated and tinned. The simple working formulas are included in the Appendix.

Accuracy of Method:

These data give some idea of the accuracy to be expected. The per cent volume conductivities are consistent within ±0.1 per cent. The first three values of *c*, for instance, are 99.4, 99.5, and 99.5, although the resistance varies by 3 and 4 in 690. These resistance variations are offset by corresponding weight variations, as it should be.

Reproducibility:

Reproducibility is exhibited by the values from spool II. Tinning increases the resistance. Part of the tin diffuses into the copper and forms a low-conductivity bronze cylinder around a reduced copper core. Also, the tinning operation affects the diameter; the "dead-soft" copper wire is stretched so that the diameter of the tinned wire is slightly less than that of the bare wire. Due to the tinning, the per cent volume conductivity of the wire is decreased from 100.5 per cent (average) to 98.6 per cent. However, when the tin and bronze are removed by acid treatment, the original conductivity is restored although the resistance of the specimen is much higher, and the diameter is much smaller than originally.

RECOMMENDATIONS

The following recommendations are offered as a result of this study.

1. Uniformly standardize the conductivity criterion for electrical conductors on the basis of per cent volume conductivity.
2. Adopt the coil-form method as a tentative standard for the determination of per cent volume conductivity of fine wire.
3. Enlarge the scope of A.S.T.M. Method B 180 beyond fine wire and ribbon for electronic devices, and revise it by including other than heavy liquids.

Acknowledgments:

The author gratefully acknowledges the valuable assistance and advice received from E. W. Greenfield, Engineer in Charge, Electrical Laboratory, and from C. J. Snyder, Engineer in Charge, Metallurgical Laboratory Anaconda Wire and Cable Co., He is particularly indebted to C. F. Carrier, in Charge of the Chemical Laboratory, who personally made the density determinations, and who suggested and used isopropyl ether as a testing liquid.

APPENDIX

LIST OF SYMBOLS

Symbol	Quantity	Unit
A	Cross-sectional area	sq. cm.
c	Per cent volume conductivity	per cent
d	Wire diameter	mils
D	Density	g. per cu. cm.
l	Length	cm. or ft.
R	D-C resistance	ohms
W	Weight	grams
ρ	Volume resistivity	ohm-cm.
ρ_s	Volume resistivity of IACS at 20 C.	ohm-cm.

FORMULAS

I. *General Case.*—Per cent volume conductivity for any cross-sectional area A, in square centimeters, and length l, in centimeters.

$$\rho = \frac{RA}{l} \text{ ohm-cm.}$$

$$\rho_s = 1.7241 \times 10^{-6} \text{ ohm-cm.}$$

$$\therefore c = 100 \frac{\rho_s}{\rho} = \frac{1.7241 \times 10^{-4} \times l}{RA} \left(\frac{\text{cm.}}{\text{ohm, sq. cm.}}\right)$$

where $A = \dfrac{W}{lD}$ sq. cm.

II. *Special Case.*—Per cent volume conductivity of round wire with diameter d, in mils, and length l, in centimeters or in feet.

$$c = 34.02 \frac{l}{Rd^2} \left(\frac{\text{cm.}}{\text{ohm, sq. mils}}\right)$$

or

$$c = 1037 \frac{l}{Rd^2} \left(\frac{\text{ft.}}{\text{ohm, sq. mils}}\right)$$

A VARIABLE CYCLE ALTERNATE IMMERSION CORROSION TESTING MACHINE*

By C. H. Mahoney[1], A. L. Tarr[1], and K. A. Skeie[1]

The recent efforts of the Society to standardize procedures for making alternate immersion tests on non-ferrous metals and alloys focus attention to equipment for making tests in accordance with the newly proposed procedures. We are all generally acquainted with various ingenious devices for such testing which usually incorporate the use of a rotating shaft to which the specimens are attached by means of strings, either directly or through the medium of a rack.

In the early stages of organizing our laboratory we reviewed the available information on alternate immersion testing methods and equipment. It was concluded that for our requirements we should design a machine which was capable of variable but accurately controlled immersion and drying cycles, in which the atmosphere to which the specimens were exposed during drying could be circulated under predetermined temperature and humidity conditions, and which was capable of testing approximately 50 samples simultaneously. Later tests with the designed equipment indicated that circulation of the atmosphere was not necessary for most testing requirements.

The machine described in this paper, Fig. 1,[2] was designed before the new A.S.T.M. Tentative Method of Alternate Immersion Corrosion Test of Non-Ferrous Metals (B 192 – 44 T)[3] was submitted for approval. It seems, however, that all requirements for both the "wet-dry modification" test and the "continuous wet modification" test are met in this equipment, and the results obtained with it in our laboratory have been so satisfactory that we are offering it to the industry in the hope that some general benefit may be realized.

Briefly, this variable cycle machine tests up to 48 specimens or clusters of specimens in separate glass solution containers which are heated by a common thermostatically controlled bath. The specimens, suspended from the rack by means of glass stirrups (see *B*, Fig. 1) are raised and lowered alternately by a sprocket chain attached to a motor-driven cam. The immersion and aeration periods are automatically controlled by means of independent time switches which permit variations in the periods ranging from a few seconds to ½ hr.

After the machine was constructed and put through trial runs, some shortcomings were observed and it was found necessary to make the following minor changes. Two 40-watt lamps with safety globes were installed inside the hood near the rear corners to improve visibility. Also, an extension shaft with flange and brake drum was bolted to the motor drive pulley and a magnetic

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* Also published in ASTM Bulletin, No. 133, March, 1945, p. 16.

[1] Chief Metallurgist, Supervisor of Metallurgical Laboratory, and Metallurgist, respectively, of Basic Magnesium, Inc., Baltimore, Md.

[2] A general assembly drawing, K-182 showing the constructional features of the machine; detail drawings K-199 and K-200; electric wiring required, drawing K-202; and a list of essential constructional materials and other items can be secured from A.S.T.M. headquarters by those requesting them.

[3] 1944 Book of A.S.T.M. Standards, Part I, p. 1860.

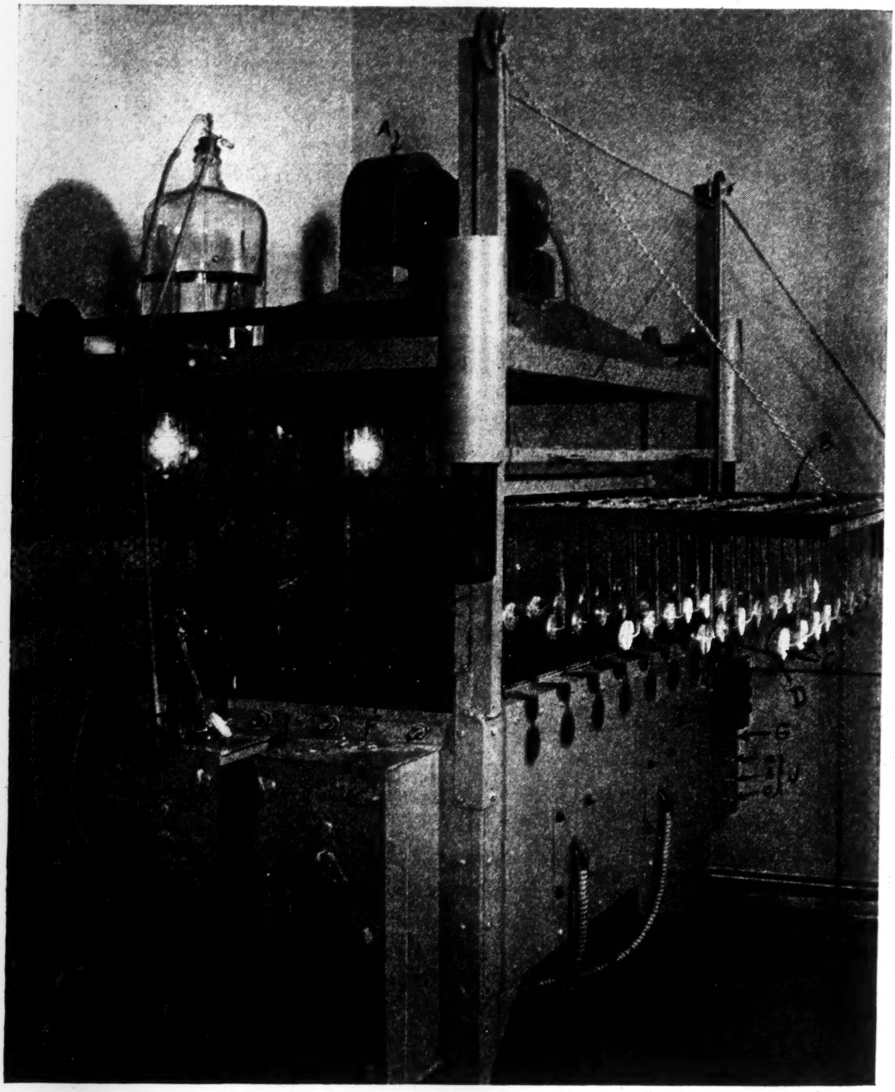

FIG. 1.—Specimen Rack in Position for Examination of Specimen.

A = blower.
B = specimen rack.
C = disk specimens.
D = glass stirrups.
E = Berzelius beaker, 1000-ml. capacity.
F = beakers set in water bath.
G = control box housing relays.
H = breaker boxes for drive-motor and heaters.
I = starting switch.
J = toggle switches for:
  a—heaters,
  b—blower,
  c—lights.
K = sprocket chain attached to motor-driven cam.
L = specimen rack carrier raised and lowered by 4 sprocket chains connected by pulley arrangement to drive sprocket.

brake (General Electric Cat. No. 5368903G4—Type CR9516462) was installed underneath the machine in order to prevent any over-carry of the driving mechanism. This solenoid brake is of a far greater capacity than is required for successful operation, but it is essential that some means of preventing excessive over-travel be used. It would probably be desirable to install some type of stirrer for the heating bath, but for temperatures not far above room temperature natural convection has given uniform temperature throughout the bath. The machine was equipped with a blower as shown in Fig. 1, *A*, but it has not been necessary to use it for the drying during the aeration phase of the cycle of normal specimens having fairly smooth contours. The blower motor is operated independently by a toggle switch and has been used only to accelerate final drying of the specimens before their removal for examination. To cushion the beakers against shock, the beaker rack was covered with a sheet of Tygon with holes cut to accommodate the test beakers. We encountered no difficulty in maintaining a relative humidity of between 50 and 70 per cent in the test chamber; however, a more accurate control may be found expedient for special test conditions.

A special feature of the machine is the wide range of cycles which can be obtained by means of the time relays used to control the immersion and draining phases. Each relay has a coarse adjustment made by placing a pawl in one of four notches, located under the right-hand corner of a calibrating plate, and a fine adjustment made by rotating a pointer on the calibrating plate. For satisfactory operation the relay should not be set for a shorter time interval than $\frac{1}{2}$ sec.[4]

POSSIBLE RANGE OF ALTERNATE CYCLES ON 60-CYCLE CURRENT.

Location of Pawl	Minimum	Maximum
Inner notch...............	$\frac{1}{2}$ sec.	29 sec.
Second notch..............	$\frac{1}{2}$ sec.	2 min. 14 sec.
Third notch...............	$\frac{1}{2}$ sec.	8 min. 48 sec.
Outer notch...............	$\frac{1}{2}$ sec.	33 min. 30 sec.

Another feature of the machine is the provision of separate beakers for each specimen or cluster of specimens. This offers a wide scope of test possibilities. Duplicate samples may be simultaneously tested in a number of corrosion media, samples of a number of different alloys or materials may be tested without fear of cross contamination by the products of corrosion from adjoining or other specimens, and the unit is admirably suited for control testing to determine if successive lots of the same material have similar corrosion resistance properties. The Berzelius type, 1000-ml. capacity beakers used in this machine are equally suited to both disk, specimens and physical test bars. Their dimensions are approximately $3\frac{1}{2}$ in. in diameter by 7 in. deep. The volume of corroding solution to specimen area provides a reasonably high ratio for most test specimens.

The design of the specimen rack prevents pendulum action of specimens without introducing undue rigidity which might cause the glass stirrups to break on sudden starts and stops of the specimen rack. The rack pulls forward from the testing cabinet to allow for rapid examination and handling of the specimens.

The roof of the hood is of substantial construction, making it possible to place heavy bottles of water or similar objects on its top. The beaker rack, at the base of the hood, is at a height which is suitable for easy manipulation of specimens and beakers.

No doubt this machine can be improved in several respects but the results in our laboratory indicate its superiority to the others which we have seen in use. It is hoped that it will answer all requirements set forth in Method B 192 prepared by the Society in its attempts to standardize alternate immersion corrosion testing.

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[4] The SG type relays (Westinghouse Style 1008539) used for energizing these time relays should be replaced by a more substantial type of relay if continuous operation is anticipated.

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON MAGNETIC PARTICLE TESTING

The papers and discussions included in the Symposium on Magnetic Particle Testing were presented at two sessions (afternoon and evening) sponsored by the Philadelphia District and held in Philadelphia on January 22, 1945. A. O. Schaefer, Executive Metallurgical Engineer, The Midvale Co., served as symposium chairman, in which capacity he arranged for the papers and discussions. Cooperating were L. E. Ekholm, chairman of the Philadelphia District, and other District members.

The purpose of the symposium was to bring together those men who had had broad experience in the various fields of application of the magnetic particle test, so that they might review the present status of magnetic particle testing and interpret the results of such testing in a variety of products.

The symposium consisted of the following nine papers:

Introduction—A. O. Schaefer
Equipment for Magnetic Particle Inspection—A. V. de Forest and C. E. Betz
Magnetic Particle Inspection—H. H. Lester
The Magnetic Particle Test as Utilized by the Railroads—L. B. Jones
Magnetic Particle Testing of Aircraft Parts—E. O. Dixon
Specifications and Procedure—A. P. Spooner
Magnetic Powder Inspection of Castings—Clyde L. Frear
Magnetic Particle Inspection of Forgings—C. J. Boyle
Miscellaneous Applications of the Magnetic Particle Test—E. A. Snader

At the afternoon session, with some 400 present, Messrs. Schaefer and R. R. Moore, U. S. Naval Aircraft Factory, acted as co-chairmen, and Messrs. Schaefer and Ekholm were co-chairmen of the evening session, which was attended by well over 500.

The papers elicited considerable discussion which contributed greatly to the information contained in the papers. The papers complete with discussion have been issued by the Society as a separate publication entitled "Symposium on Magnetic Particle Testing."

PROPERTIES OF HIGHLY HYDRATED DOLOMITIC MASONRY LIMES AND CERTAIN OF THEIR CEMENT-LIME MORTARS

By G. J. Fink[1] and Emil Trattner[1]

Synopsis

This report presents the results of tests of the six commercially available masonry limes of a new type, the highly hydrated dolomitic limes. Data are presented on the chemical and physical properties of the limes, on the physical properties of mixtures in the proportion of 1 bag of portland cement to 2 bags of lime tested as masonry cements, and on 1:2:9 mortars prepared from the limes. In order to simulate more nearly the conditions of job use, additional 1:2:9 mortars were also tested 30 min. after the initial mixing and after the mortars had been subjected to suction for 1 min. All the limes contained small percentages of unhydrated oxides and showed low expansions in the autoclave; all had high plasticities and high water retentivities. All the mortars made with these limes exhibited good workability and unusually high water retentivity.

Several manufacturers, within the past five years, have placed on the market a new type of hydrated lime. This product is a highly hydrated dolomitic lime which differs from the normal dolomitic hydrated limes in that the major percentage of the magnesium oxide is hydrated. Methods for attaining more complete hydration of the magnesium oxide of dolomitic limes were suggested as early as 1901.[2] Renewed attention was directed to this subject in the late thirties, particularly after the publication of Research Paper No. 1022[3] of the National Bureau of Standards which describes methods for determination of the unhydrated oxide content of limes, presents data on the rate of hydration of magnesia under various conditions, and points out some differences that might result from the use of the completely and the incompletely hydrated limes.

It has been more or less common practice in the trade to refer to the new limes as pressure hydrated or autoclaved limes. This term, however, is a misnomer because some are produced by methods which do not involve the use of pressures above atmospheric. For the purpose of identification in the present discussion, the new products are designated as highly hydrated limes. Two types are now produced for structural purposes, one of which is intended for use as a finishing lime and the other for use in masonry.

The research staff of the National

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[1] Research Associates for National Lime Assn., at the National Bureau of Standards.

[2] Some of the patents of interest are U. S. Patent Nos. 678,500, July 16, 1901; 955,814, April 19, 1910; 1,284,505, Nov. 12, 1918; 2,309,168, Jan. 26, 1943; 2,356,760, August 29, 1944; Swiss Patent No. 52,373, May 6, 1910; Dutch Patent No. 33,805, May 15, 1934. The subject is also mentioned by G. J. Fink, "Science In An Old Industry—Lime Manufacture," paper presented at the annual meeting of American Association Advancement Science, 1926.

[3] L. S. Wells and K. Taylor, "Hydration of Magnesia in Dolomitic Hydrated Limes and Putties," *Journal of Research*, National Bureau of Standards, Vol. 19, No. 2, August, p. 215, 1937 (RP 1022); also, "Studies of Heat of Solution of Calcium and Magnesium Oxides and Hydroxides," *Journal of Research*, National Bureau of Standards, Vol. 2, No. 2, August, p. 133, 1938 (*RP* 1121).

Lime Association Fellowship at the National Bureau of Standards is conducting a survey of the commercial limes marketed for structural uses. This report presents the results of that part of the investigation which was undertaken to obtain information on the properties of the six commercially available highly hydrated dolomitic limes of the masonry type and of certain mortars in which these limes were components. Some of the properties of one of these limes and its mortars were reported in an earlier paper.[4]

TABLE I.—CHEMICAL COMPOSITION OF THE LIMES.

Lime	CaO, per cent	MgO, per cent	Acid Insoluble + SiO_2, per cent	R_2O_3, per cent	CO_2, per cent	Combined H_2O, per cent	H_2O at 110 C., per cent	Unhydrated Oxides Calculated, per cent
No. 23	42.4	29.7	1.3	0.5	0.8	25.1	0.1	3.3
No. 25	42.4	28.7	1.9	0.7	0.5	25.1	0.1	2.5
No. 28	42.9	29.7	0.3	0.2	0.3	26.2	0.1	1.6
No. 34	44.1	30.5	0.3	0.2	1.0	23.1	0.1	9.5
No. 36	42.8	29.1	0.2	0.1	2.8	23.2	0.2	5.2
No. 51	42.2	29.1	1.6	0.4	2.2	24.0	0.4	3.6
Average	42.8	29.3	0.9	0.3	1.2	24.6	0.2	

THE LIMES

Samples of the six commercially available limes, originating from three widely separated lime-producing centers, were obtained in bag quantities directly from the manufacturers. The samples were described as representative of average production at each plant. Upon receipt, the materials were stored in airtight containers until used.

Chemical Composition:

The chemical analyses of the limes were made in accordance with the A.S.T.M. Standard Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 – 44,)[5] and the unhydrated oxide content was calculated in accordance with Proposed Amendment 1 (2–2–40) to Federal Specification for Hydrated Lime for Structural Purposes, SS-L-351.

The analytical data are listed in Table I. It may be noted that there is a decided similarity in composition other than the percentages of unhydrated oxide. The values for the latter range from 1.6 to 9.5 per cent.

Expansion in Autoclave:

Owing to the fact that there are no satisfactory test procedures for ascertaining volume change characteristics of hydrated limes alone, the expansive properties of the limes when subjected to steam pressures were determined by testing portland cement-lime mixtures essentially in accordance with A.S.T.M. Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 – 43).[6] The portland cement used in these tests showed an expansion of 0.11 per cent. After preliminary tests of neat pastes and of mortars, a neat paste consisting of two parts of portland cement and one part of lime, by weight, was selected for the present tests for the reason that specimens of this mixture possessed adequate strength, and breakage during handling was not excessive. The following variation in mixing procedure which is better adapted to neat cement-lime pastes was used:

500 g. of cement and 250 g. of lime were vigorously shaken in a 2-qt. jar, contents of jar poured onto a dry, smooth, flat surface, and troweled back and forth four times to break up lumps and to assure thorough mixing. The mixture was heaped into a mound and an inner and outer crater formed with

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[4] G. J. Fink, "The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 780 (1944).

[5] 1944 Book of A.S.T.M. Standards, Part II, p. 109.

[6] 1944 Book of A.S.T.M. Standards, Part II, p. 44.

the handle of the trowel. A measured amount of water was poured into the craters and the material was turned into the craters within 30 sec. After the batch had remained undisturbed for 60 sec. to permit wetting of particles, it was vigorously mixed with both hands for 3 min., then left undisturbed for 60 sec. and finally vigorously remixed for 60 sec. This procedure made it possible to prepare neat cement-lime pastes of similar consistencies with approximately the same percentages (32 ± 1 per cent) of water regardless of the limes used.

TABLE II.—PROPERTIES OF THE LIMES.

Lime	Unhydrated Oxides, per cent	Autoclave Expansion Linear, per cent	Fineness Retained on Sieve, per cent		Water Retentivity, per cent	Lime Putty, 30 min. After Wetting		Lime Putty Soaked Over-night	
			No. 30	No. 200		Consistency[a]	Plasticity	Consistency[a]	Plasticity
No. 23.....	3.3	0.18	0.5	17.2	96	107	280	107	410
No. 25.....	2.5	0.21	0	12.9	97	90	450	91	450
No. 28.....	1.6	0.24	0	1.2	96	94	230	97	290
No. 34.....	9.5	0.82	0	17.1	94	81	200	87	280
No. 36.....	5.2	0.22	0	13.5	94	90	400	90	400
No. 51.....	3.6	0.26	0	0.4	94	87	440	90	550
Average....					95		330		390

[a] Parts water per 100 parts lime ,by weight.

The data are listed in Table II. The linear expansions of the specimens of the neat 2:1 mixes from the five limes containing not more than 5.2 per cent unhydrated oxides ranged from 0.18 to 0.26 per cent and averaged 0.22 per cent. The expansion with lime No. 34, which contained 9.5 per cent unhydrated oxides, was 0.82 per cent.

Fineness:

The fineness tests were made in accordance with the procedure described in the A.S.T.M. Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 – 38 T),[7] except that three additional sieves were used in order to obtain additional information about the particle size distributions.

The sieve analyses of the six limes are listed in Table III, and for convenience the percentages retained on sieves Nos. 30 and 200 are also listed in Table II.

Plasticity:

The Emley plasticity figures for the limes were determined in accordance with A.S.T.M. Methods C 110. In this method the putties are soaked overnight. In addition, plasticity figures were also obtained for lime putties tested 25 to 30 min. after wetting.

TABLE III.—SIEVE ANALYSES OF THE LIMES.

Lime	Per Cent Passing Sieve				
	No. 30	No. 50	No. 100	No. 200	No. 325
No. 23.......	99.5	95.5	88.0	82.8	82.1
No. 25.......	100.0	99.2	96.1	87.1	86.4
No. 28.......	100.0	99.7	99.4	98.8	98.1
No. 34.......	100.0	99.3	87.6	82.9	82.2
No. 36.......	100.0	94.7	90.6	86.5	86.0
No. 51.......	100.0	100.0	99.9	99.6	97.7

The data are listed in Table II. It may be noted that all the putties, tested 25 to 30 min. after wetting, had plasticity figures of 200 or more. The high plasticity exhibited by the putties without prolonged soaking is characteristic of the highly hydrated limes. In most cases the increases in plasticity resulting from the overnight soaking were relatively small.

Water Retentivity:

The water retentivity tests were made in accordance with the method described in A.S.T.M. Tentative Specifications for Masonry Cement (C 91 – 44 T).[8] The initial flow was limited to 110 ± 3 per cent.

The data are listed in Table II. The water retentivity values ranged from 94 to 97 per cent, values much higher than for most limes of other types.

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[7] 1944 Book of A.S.T.M. Standards, Part II, p. 1238.

[8] 1944 Book of A.S.T.M. Standards, Part II, p. 1206.

CEMENT-LIME MORTARS

Materials:

The portland cement used in making all mortars was the same as used in the autoclave expansion tests and was obtained directly from the manufacturer. It fulfilled the A.S.T.M. specification requirements for type I cement.[9] Tests of various shipments of this particular brand received over the past two years have shown it to be of average strength and uniform in its characteristics.

The standard Ottawa sand conformed to that designated in A.S.T.M. Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 – 44).[10] The masonry sand was a commercial sand from the Philadelphia area and fulfilled the requirements of A.S.T.M. Standard Specifications for Aggregate for Masonry Mortar (C 144 – 44).[11] The results of the tests on this sand are presented in Table IV.

The limes used were those already described.

General Test Methods:

The procedures used in proportioning, mixing, curing and testing of the mortars were in conformity with those described in A.S.T.M. specifications for masonry cement C 91 and the corresponding Federal specification SS-C-181b, except for the divergencies specifically described in connection with the particular tests. All mixtures were prepared and all tests were performed in a laboratory in which the temperature was maintained at 21 C. ± 2 C. and the relative humidity at 55 ± 5 per cent. The atmosphere of the damp closet was maintained at the same temperature as the laboratory and at a relative humidity of 95 ± 3 per cent. The water of the curing tanks was kept flowing continuously at a low rate and was maintained at the same temperature as the laboratory. All materials were at the temperature of the laboratory when used.

Specimens and Test Methods:

Mortar M—Cement-Lime Mixtures Tested as Masonry Cements.—In the cement-lime mortars made with standard Ottawa sand (mortar M) the portland cement - lime mixtures were tested as masonry cements. The portland cement and lime were mixed in the proportion of one bag (94 lb.) of cement to two bags (100 lb.) of lime, and one part of the resulting cementitious material was mixed with three parts by weight of sand. Two separate batches of mortar were prepared with each lime, using 1500 g. of sand, and all test procedures conformed to those described in Federal Specifications for Masonry Cement, SS-C-181b and the A.S.T.M. Tentative Specifications C 91 – 44 T. The range in consistencies was limited to an initial flow of 110 ± 3 per cent. The specimens for the 7-day compressive strength tests were molded from the unused portion of the same batch as that

TABLE IV.—PROPERTIES OF MASONRY SAND.

Fineness, per cent passing sieve					
No. 4	No. 8	No. 16	No. 30	No. 50	No. 100
100	98	88	64	26	5

Fineness modulus = 2.20.
Organic impurities = approximately Fig. 2 of A.S.T.M. Standard Method of Test for Organic Impurities in Sands for Concrete (C 40 – 33), 1944 Book of A.S.T.M. Standards, Part II, p. 438.
Weight per cu. ft., damp loose = 84 lb.; Weight per cu. ft., air dry = 90 lb.
Weight of dry sand in 1 cu. ft. damp loose sand = 82 lb.
Mortar strength, 7-day = 1980 psi.; 28-day = 3590 psi., as compared with graded Ottawa sand, 7-day = 1850; 28-day = 3200 psi.
Mortar strength as prescribed by A.S.T.M. Standard Specifications for Aggregate for Masonry Mortar (C 144 – 44).

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[9] Standard Specifications for Portland Cement (C 150 – 44) 1944 Book of A.S.T.M. Standards, Part II, p. 1.

[10] 1944 Book of A.S.T.M. Standards, Part II, p. 70.

[11] 1944 Book of A.S.T.M. Standards, Part II, p. 232.

on which water retentivity tests were made. This was sufficient for only five 2-in. cubes. The six cubes for 28-day tests were molded from a second batch immediately after measurement of the flow.

Mortar N—1:2:9 By Volume, Masonry Sand.—The 1:2:9 masonry sand mortars (mortar N) were of the proportions of one bag of cement, two bags of lime and 9 cu. ft. of damp loose sand. The dry ingredients for each mix were weighed. The amount of sand used in each mix was calculated on the assumption that 1 cu. ft. of damp loose sand contains 80 lb. of air-dry sand. The value of 80 lb. was used in order to bring the tests into accord with the requirement of the masonry code of the American Standards Association.[12] The same procedure as for mortar M was used in the preparation and testing of these mortars, except that the size of the batches was increased by using 1800 g. of sand in order to yield sufficient material to mold 6 cubes.

The specific weights were determined as follows: A cylindrical brass cup approximately 3 in. in diameter and 4 in. high and having a capacity of 500 ml. was filled with the mortar which had been mixed and adjusted to a flow of 110 ± 3 per cent. The specific weight was calculated from the weight of this volume of mortar. The results of the tests from filling the cup according to two different procedures were compared. One procedure involved vibrating the cup on an electrical vibrator while it was being filled in accordance with the procedure used by Blaine, Yates, and Dwyer of the National Bureau of Standards.[13] The second method involved tamping of each of three successive layers of the mortar with a hard-rubber prism, 1.0 by 0.5 in. in cross-section, while the cup was being filled. The comparative values obtained by these two methods are designated as "tamped" and "vibrated" in the tabulation.

Mortar O—Modified Mortar N.—The 1:2:9 mortars were duplicates of mortar N in respect to proportion of constituents. The materials were mixed with the predetermined amount of water required to yield mortars which, after standing 30 min. and remixing, would give a flow of 110 ± 3 per cent. The initial mixing was performed just as in the case of the previous mortars. The container was then covered with a damp cloth and allowed to stand for 30 min. from the time of wetting. The mortars were then remixed for one min. and tested for water retentivity. The cubes were molded from the mortars taken from the suction dish. This procedure was followed in order to gain some information relative to their probable compressive strength under conditions more nearly simulating those obtaining when the mortars are used on the job and after they are placed between bricks of medium suction characteristics.

Results of Tests:

Mortar M—Cement-Lime Mixtures Tested as Masonry Cements.—The results of the tests on mortar M are given in Table V.

The quantity of mixing water required to obtain the desired consistency varied from 15.3 per cent to 17.6 per cent of the combined weights of sand and cementitious material. The mortar from the lime containing the greatest percentage of unhydrated oxide (lime No. 34) required the smallest quantity of mixing water and possessed the highest compressive strength as well as the lowest water retentivity. The mortar containing the greatest percentage of water (No. 23), in turn, was one of the wo having the highest water retentivities, and it yielded cubes having the lowest strength. No relation between water content and compressive strength was apparent among the other four mortars.

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[12] American Standard Building Code Requirements for Masonry, A41.1-1944, sponsored by the National Bureau of Standards and published as Miscellaneous Publication M174 (1944).

[13] R. L. Blaine, J. C. Yates, and J. R. Dwyer, "The Testing of Portland Cements Containing Interground Vinsol Resin," see p. 732.

TABLE V.—PROPERTIES OF CEMENT-LIME MIXTURES—TESTED AS MASONRY CEMENTS—MORTAR M.

Proportions of Cementitious Materials = 1 bag portland cement + 2 bags hydrated lime.

Composition of Mortar = 1 part cementitious material + 3 parts Standard Ottawa Sand, by weight.

Lime	Mixing Water, per cent[a]	Initial Flow, per cent	Water Retentivity, per cent	Compressive Strength, psi.		Coefficient of Variation of Strength Values, per cent		Ratio of 7-day Strength to 28-day Strength
				Average 5 Cubes, 7 days	Average 6 Cubes, 28 days	5 Cubes, 7 days	6 Cubes, 28 days	
No. 23	17.6	108	93	750	990	2.2	1.6	0.76
No. 25	16.4	107	93	840	1130	3.3	1.8	0.74
No. 28	16.0	110	91	870	1160	1.3	1.5	0.75
No. 34	15.3	111	89	980	1220	2.7	2.4	0.80
No. 36	16.0	112	92	940	1200	1.7	1.7	0.78
No. 51	15.5	108	90	850	1110	1.8	0.9	0.77
Average	16.1		91	870	1140	2.2	1.7	0.77

[a] By weight of dry materials.

The water retentivity values of all the mortars were relatively high, ranging from 89 to 93 per cent, with an average of 91 per cent. (A.S.T.M. and Federal Specification requirements for masonry cement are 70 and 65 per cent, respectively.) The values for retentivity showed a general parallelism with the mixing water content.

The average 7-day compressive strength of the six mortars was 870 psi. (coefficient of variation 9.3 per cent) and 28-day average was 1140 psi. (coefficient of variation 7.2 per cent). The 7-day strengths were all far above the 500-psi. 7-day requirement for type II masonry cement of Federal Specification SS-C-181b and with one exception (990 psi.), the 28-day strengths were well above the 1000 psi. 28-day requirement for type II of that specification. Five of the limes were thus shown to yield 1:2 cement-lime mixtures which qualify as type II masonry cements under this specification. The mixtures from all six limes greatly exceeded the minimum strength requirement of A.S.T.M. Tentative Specifications C 91 – 44 T of 400 psi. for 7 days and 750 psi. for 28 days.

TABLE VI.—PROPERTIES OF 1:2:9, BY VOLUME, MASONRY SAND MORTARS—MORTAR N.

Composition of mortar: 1 bag portland cement + 2 bags hydrated lime + 9 cu. ft. masonry sand.

Lime	Mixing Water, per cent[a]	Initial Flow, per cent	Mortar Yield From 1 ton of Lime, cu. yd.	Specific Weight, lb. per cu. ft.		Water Retentivity, per cent	Compressive Strength, psi.		Coefficient of Variation of Strength Values, per cent		Ratio of 7-day Strength to 28-day Strength
				Tamped	Vibrated		Average 6 Cubes, 7 days	Average 6 Cubes, 28 days	6 Cubes, 7 days	6 Cubes, 28 days	
No. 23	18.8	107	6.31	127.1	126.5	94	425	620	3.3	1.3	0.69
No. 25	18.4	107	6.27	128.0	127.2	94	470	660	1.5	2.9	0.70
No. 28	18.0	112	6.36	125.2	124.9	93	485	710	2.9	1.0	0.68
No. 34	17.1	110	6.36	125.1	124.6	88	550	760	1.1	2.0	0.72
No. 36	18.0	109	6.43	124.4	123.6	95	510	740	1.8	0.8	0.69
No. 51	17.5	109	6.34	126.1	124.5	91	510	680	2.6	0.9	0.75
Average	18.0		6.39	126.0	125.2	92	490	695	2.2	1.5	0.71

[a] By weight of dry materials.

The ratios of the 7-day to 28-day strengths were very nearly the same for all the limes, ranging from 0.75 to 0.80 with an average of 0.77. These ratios were vastly different from those reported in a previous paper,[4] where the range was 0.50 to 0.69 with an average of 0.61 for the five limes tested.

The cubes made from the individual mortars were unusually uniform in strength, having an average coefficient of variation of 2.2 per cent for 7-day cubes and 1.7 per cent for 28-day cubes. This uniformity is probably explained by the excellent workability of the mortars from the highly hydrated limes which made possible the production of remarkably uniform test specimens. This effect was apparent throughout all the tests on these limes.

TABLE VII.—PROPERTIES OF 1:2:9, BY VOLUME, MASONRY SAND MORTARS—MORTAR O, MODIFIED MORTAR N.

Cubes for compressive strength were molded from mortars which had been subjected to suction for 1 min.
Composition of mortar: 1 bag portland cement + 2 bags hydrated lime + 9 cu. ft. masonry sand.

Lime	Mixing Water, per cent[a]	Initial Flow After Standing 30 min., per cent	Flow After Suction, per cent	Water Retentivity, per cent	Compressive Strength, psi.		Coefficient of Variation of Strength Values, per cent		Increase in Strength over Mortar N, per cent		Ratio of 7-day Strength to 28-day Strength
					Average 5 Cubes, 7 days	Average 5 Cubes, 28 days	5 Cubes, 7 days	5 Cubes, 28 days	7 days	28 days	
No. 23	18.8	107	98	92	520	700	2.3	2.4	22.6	13.6	0.74
No. 25	18.6	110	101	92	520	740	3.5	1.9	11.7	12.9	0.70
No. 28	18.0	110	103	94	520	750	3.3	2.6	6.6	5.7	0.70
No. 34	17.5	112	103	91	570	760	1.6	3.1	2.7	0.7	0.75
No. 36	18.2	110	103	93	530	740	1.0	0.6	4.4	0.0	0.72
No. 51	18.1	109	102	93	530	670	2.9	1.5	4.1	−1.3	0.79
Average	18.2			92	530	730	2.3	2.0	8.7	5.3	0.73

[a] By weight of dry materials.

Mortar N, 1:2:9 by Volume, Masonry Sand.—The results of the tests in mortar N are given in Table VI.

The variations in the quantities of water required to yield mortars of the desired consistency (flow 110 ± 3 per cent) were appreciably less (17.1 to 18.8 per cent) than in the case of the standard sand mortars and the general trend was for the mortars with lower water content to show higher compressive strengths.

The specific weight values determined by the two different methods previously described agreed very closely although the values obtained by using the tamping procedure were slightly but consistently higher than those obtained by use of the vibration method for filling the measuring cup.

The water retentivity values were unusually high as compared with those obtained with the five limes discussed in the previous report.[4] The average for the 1:2:9 mortars with the latter limes was 72 per cent, with a range from 65 to 82 per cent, whereas, the values for the present mortars ranged from 88 to 94 per cent, with a mean of 92 per cent.

The workability characteristics of all these mortars, as in the case of the others, were such that excellent test cubes were produced with ease and this perhaps explains the small spread in the compressive strengths of the six cubes of each mortar, as indicated by the low coefficients of variation. These averaged only 2.2 and 1.5 per cent for the 7-day and 28-day cubes, respectively.

A comparison of the compressive strengths of the mortars from all of the limes shows only very slight differences. The average 7-day strength for all the mortars with the six limes was 490 psi., with a coefficient of variation of 8.7 per cent, and the average 28-day strength was 695 psi., with a coefficient of variation of 7.5 per cent.

There was also evident a uniformity among the ratios of 7-day to 28-day strengths. These ranged from 0.68 to 0.75, with an average of 0.71.

It may be noted from the 28-day strengths that all of these mortars could be classified as type B under the American Standard Code,[12] in spite of the fact that they are type C mortars under the proportion classification of this code.

Mortar O—Modified Mortar N.—The results of tests on mortar O are given in Table VII.

Several significant facts are obvious. In the first place, the water retentivities of the 30-min. mortars were found to be approximately the same as those of mortar N which was tested immediately after mixing. The averages were identical for the two different sets of mortars and this similarity indicates that allowing the mixes to stand for 30 min. did not appreciably affect the water retentivity.

In the second place, there was even less difference in the compressive strengths of these mortars from the six limes than was the case with mortar N. The average 7-day strength for mortar O from the six limes was 530 psi., with a coefficient of variation of only 3.7 per cent, and the average 28-day strength was 730 psi., with a coefficient of variation of only 4.8 per cent. This result might have been expected because the amount of what might be called excess water, which varied with different mortars, was removed by suction, thus rendering the mortars from the different limes more uniform in their water content.

The strength values were generally higher, and the increases in the strengths of these mortars over the strengths of the mortars molded immediately after mixing ranged between 2.7 and 22.6 per cent for the 7-day cubes and between −1.3 and 13.6 per cent for the 28-day cubes. These wide variations might be attributable, as previously noted, to appreciable differences in the quantity of excess water in the mortars made with the different limes.

The ratios of the 7-day strengths to the 28-day strengths show a somewhat greater spread (0.70 to 0.79, average 0.73), than the corresponding ratios for the mortars molded immediately after mixing.

CONCLUSIONS

It is apparent from the data presented that all of the six commercially available highly hydrated dolomitic masonry limes and their 1:2:9 mortars show an unusual similarity, despite the fact that the limes originated at three widely separated lime producing centers. The following specific conclusions also appear to be warranted:

The Limes:

1. The chemical compositions of the limes were very similar.

2. The calculated unhydrated oxide content of five of the limes ranged between 1.6 and 5.2 per cent and the linear expansions of autoclaved test bars of neat pastes composed of 2 parts portland cement and 1 part lime, by weight, were from 0.18 to 0.26 per cent. The unhydrated oxide content of the sixth lime was 9.5 per cent and its linear expansion 0.82 per cent.

3. The water retentivity values ranged from 94 to 97 per cent.

4. The plasticity figures for the putties tested 25 to 30 min. after wetting ranged from 200 to 450 and those of the putties tested after soaking overnight were from 290 to 550.

Cement-Lime Mixtures, Tested as Masonry Cements:

5. Mixtures of each of the six limes when proportioned in the ratio of 1 bag

of portland cement to 2 bags of hydrated lime and tested as masonry cements have water retentivities ranging from 89 to 93 per cent, values which greatly exceed the requirements of 65 and 70, respectively, of the Federal and A.S.T.M. Tentative Specifications for Masonry Cement.

6. The mortars from five of the six limes had 28-day compressive strengths exceeding the 1000 psi. requirement of the Federal specifications for type II masonry cement. The value for the sixth lime was 990 psi. The ratios of 7-day to 28-day compressive strengths ranged from 0.74 to 0.80, with an average of 0.77.

Cement-Lime Mortars:

7. The 1:2:9, by volume, masonry sand mortars, tested immediately after mixing, had unusually high water retentivities. The values were from 88 to 95 per cent with an average of 92 per cent.

8. The cubes made from the mortars from the six limes had an average 28-day compressive strength of 695 psi. with a coefficient of variation of 7.5 per cent. All strengths were above the minimum requirement of 600 psi. for type B mortars of the American Standard Building Code Requirement for Masonry. The ratios of 7-day to 28-day strengths ranged from 0.69 to 0.75 with an average of 0.71.

9. The 1:2:9, by volume, masonry sand mortars which were allowed to stand 30 min. after the initial mixing possessed approximately the same water retentivities as the mortars tested immediately after mixing. These values ranged from 91 to 94 per cent with an average of 92 per cent.

10. The 1:2:9, by volume, masonry sand mortars, allowed to stand 30 min. and then subjected to suction for 1 min., had somewhat higher and more uniform compressive strengths than the corresponding mortars tested immediately after mixing. The average at 28 days was 730 psi., with a coefficient of variation of 4.8 per cent. The ratios of 7-day to 28-day strengths ranged from 0.70 to 0.79 with an average of 0.73.

THE TESTING OF PORTLAND CEMENTS CONTAINING INTERGROUND VINSOL RESIN

By Raymond L. Blaine,[1] Jason C. Yates,[1] and John R. Dwyer[1]

Synopsis

Tests were made on 64 commercially manufactured air-entraining portland cements containing interground Vinsol resin. The quantities of Vinsol resin in these cements ranged from 0.007 to 0.123 per cent. Fineness values determined by means of the Wagner turbidimeter ranged from 1500 to 2400 sq. cm. per g. The 1:3 tension test mortars made according to regular portland cement specifications had flows ranging from 57 to 128 per cent, whereas untreated cements had flows of 65 to 75 per cent. Tensile strength mortars were also proportioned with just enough water to give the 65 to 75 per cent flow characteristic of untreated cements. The 1 to 2.75 compressive strength mortars were proportioned with the 0.53 water-cement ratio required in previous specifications and also with just enough water to have a flow of 100 to 115 per cent. The report indicates the water requirements and strengths at different ages of the different cements when proportioned and tested by different methods. The strengths of the different cements varied over a wide range. For example, the 7-day tensile strengths ranged from 250 to 530 psi. and the 7-day compressive strengths of plastic mortars ranged from 1400 to 5330 psi. The compression test indicated a much greater difference in the relative strengths of the different cements than did the tension test.

Measurements were made of the air entrained in the various mortars used for strength test specimens as well as the air entrained in the proposed performance test mortar and in concrete. The compressive strength mortars had from 1 to 10 times as much entrained air as the concrete made of the respective cements and the difference in ratios of the amount of air entrained in the tension test mortar to that in concrete was even greater.

The 1:4 standard test mortars made of the Vinsol resin cements had from 6 to 23 per cent entrained air whereas the concrete made from these cements had from 1.5 to approximately 15 per cent entrained air. The ratio of air entrained in the 1:4 test mortar to that in concrete varied from 1.5 to 4.9. The duplicability of air contents of the 1:4 mortars was as good as or better than was found with the other mortars tested.

The tests reported furnish information supporting some of the recent changes in methods of test and specification requirements of Vinsol resin cements.

The commercial production of air-entraining portland cements containing small quantities of Vinsol resin interground in the manufacturing process is a rather recent development. Soon after their first use it became apparent that the existing specifications did not include adequate criteria for their evaluation

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[1] National Bureau of Standards, Washington, D. C.

and that new tests and testing techniques should be provided. The investigation described in this paper was undertaken to obtain information on methods of testing.

At the time this investigation was started both A.S.T.M. and Federal specifications required that, for a given cement, the water requirement of the neat cement paste be used in determining the amount of water for the cement-sand mortar used for tensile strength specimens. The original intent of this method of proportioning of the regular portland cements was to take cognizance of the different water requirements of the different cements and at the same time produce mortars of about the same consistency. However, these tension-test mortars made of Vinsol resin cements were found to be more workable than mortars made of the regular cements. With some cements the mortar was so fluid that some of it was forced out of the mold when an attempt was made to apply the 15 to 20 lb. pressure specified for molding the test specimens. In those cases it was impossible to mold the specimens according to specification methods. Similarly, the plastic mortar used in making the compressive strength test specimens was adjudged too wet when made with the water-cement ratio of 0.53 required by specifications in force at the time this investigation was begun.

The effect of change of the water-cement ratio on strength of the acceptance test mortars of the air entraining cements was not fully known. Because the strength requirements in cement specifications are of particular interest to both producer and consumer, it was believed desirable to make a study of the water requirements and strengths of a large number of Vinsol resin cements.

Sixty-four commercially manufactured air-entraining portland cements containing interground flake Vinsol resin were procured from 57 mills. Tests were also made on nine cements not reported as containing Vinsol resin or other air-entraining agents in order to obtain a basis for comparison of some of the properties. Of these nine untreated cements, three were type III or high-early-strength cements. These type III cements were chosen because they were of a fineness comparable to the finer of the Vinsol resin cements and also because it was believed that the plastic properties of these cements were more like those of the Vinsol resin cements than of the other untreated cements.

One of the distinguishing properties of Vinsol resin cement is the entrainment of air in mortars and concretes made with the cement. When Vinsol resin cement was first manufactured, it was believed adequate to specify the maximum and minimum quantities of Vinsol resin in the cement in order to maintain the air content in concrete within suitable limits. Later experience showed that there are other variables besides the quantity of Vinsol resin affecting the air entraining property of the cement. This led to a performance test[2] in which the air content of a 1:4 mortar was the criterion of the probable air content of concrete made of that cement. A study was made of the relation of the air content of the proposed 1:4 mortar to that of concrete. Determinations were also made of the air contents of neat pastes and of various mortars used for strength tests in a study, first, of the relations of air contents of the pastes and mortars to other properties, and, second, of the possibility of the use of tests other than the proposed air-entrainment test.

TESTS AND TEST METHODS

Fineness:

The fineness values of these cements

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[2] Tentative Method of Test for Air Content of Portland-Cement Mortar (C 185 – 44 T), 1944 Book of A.S.T.M. Standards, Part II, p 1227.

were determined by means of the Wagner turbidimeter and also by means of the Lea-Nurse air-permeability apparatus. The turbidimeter fineness values were determined in accordance with the methods prescribed in the A.S.T.M. Standard Method of Test for Fineness of Portland Cement by the Turbidimeter (C 115 - 42).[3] In the air-permeability fineness tests, a 2.54-cm. diameter cell with a bed depth of 1.85 cm. was used. The size of sample tested was varied to produce a test bed having an index of compaction (**1**)[4] of 1 to 3 mm. The regular Lea-Nurse equation (**2**) was used in calculating the fineness values. Duplicate determinations of fineness were made by each method for each of the cements.

Chemical Tests:

The amount of chloroform-soluble material of each of the Vinsol resin cements was determined according to the method prescribed in Section 32 of the A.S.T.M. Standard Methods of Chemical Analysis of Portland Cement (C 114 - 42).[5] Chemical analyses for Vinsol resin were also made by the methoxyl method of A.S.T.M. Tentative Methods of Chemical Analysis of Portland Cement (C 114 - 44 T)[6] on 13 of the cements.

Consistency:

Neat Pastes.—The amount of water required to produce normal consistency in a cement paste was determined for each of the cements according to the method prescribed in the A.S.T.M. Standard Method of Test for Normal Consistency of Hydraulic Cement (C 187 - 44).[7]

With most of the cements the water requirements were checked by a second operator, but with some cements, the same operator made all of the determinations. Three or more determinations were made with each of the cements.

Mortars.—The consistencies of the mortars were determined by means of the 10-in. flow table according to the method prescribed in A.S.T.M. Standard Method of Test for Compressive Strength of Hydraulic-Cement Mortars (C 109 - 44),[8] except that a slight deviation in the test procedure occurred in the method of filling the flow mold. The flow mold was filled in three layers by rather forcibly projecting the mortar into the cup by means of a "$\frac{1}{4}$-cup" measuring scoop. Very little if any tamping or compressing was necessary to obtain uniform filling. Because of the tendency of some of the mortars to stiffen, a close adherence to the 30-sec. time interval specified between the completion of mixing and the start of flow was very important with these cements. A flow determination was made on each of two batches on each of the mortars of each of the cements.

Strength:

Tensile Strength.—Tensile strength specimens were made from mortars of two consistencies and in accordance with the methods prescribed in A.S.T.M. Standard Method of Test for Tensile Strength of Hydraulic-Cement Mortars (C 190 - 44)[9] except as described below. Three specimens were made for testing in tension at each of the ages of 3, 7, and 28 days from each of the cements and each of the two mortars. Three specimens were stored for test at a later age. The two mortars were as follows:

1. Mortar A, proportioned 1:3 by weight of cement to (20-30) Ottawa sand, was gaged with the quantity of water as required by the table in Section 6 of Method C 190 - 44. Inasmuch as it was impossible to apply the specified 15 to 20-lb. pressure on many of these

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[3] 1944 Book of A.S.T.M. Standards, Part II, p. 47.

[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 752.

[5] 1942 Book of A.S.T.M. Standards, Part II, p. 14.

[6] 1944 Book of A.S.T.M. Standards, Part II, p. 1214.

[7] *Ibid*, p. 58.

[8] 1944 Book of A.S.T.M. Standards, Part II, p. 76.

[9] *Ibid*, p. 70.

mortars without forcing mortar out of the mold, the amount of pressure used was varied with the need of the different cements.

2. Mortar B, proportioned 1:3 by weight of cement to (20–30) Ottawa sand, was gaged with enough water to secure a flow of 70 ± 5 per cent. Preliminary tests had indicated that normal portland cements not containing Vinsol resin had flows within this range of values when gaged with the quantity of water specified in Table II of Section 6 of Method C 190 - 44. When the flow of mortar A was within the 70 ± 5 per cent range chosen for mortar B, the same specimens served for both mortars A and B.

The mortar batches used for the flow determinations were not used in making the briquets because of the rapid stiffening of some of these mortars.

Compressive Strength.—Compressive strength specimens were made in accordance with the methods prescribed in Method C 109 except with some deviations from the regular test methods as noted below. Mortars were made of two consistencies as follows:

1. Mortar C, a plastic mortar proportioned 1 to 2.75 by weight of cement to graded Ottawa sand, was prepared with 53 per cent water by weight of cement. This is the mortar specified in Tentative Method of Test for Compressive Strength of Portland-Cement Mortars (C 109 - 43 T),[10] and in A.S.T.M. Tentative Specifications for Treated Portland Cement for Concrete Pavements (C 175 - 42 T),[11] in force when this work was started.

2. Mortar D, a plastic mortar proportioned 1 to 2.75 by weight of cement to graded Ottawa sand, was gaged with the amount of water needed for a flow of 100 to 115 per cent. This mortar corresponds with that specified in Method C 109 - 44, which method is required by the latest revision of Tentative Specifications C 175,[12] proposed after the work was started.

For both of these mortars the flow was determined by means of the 10-in. flow table and, simultaneously, a volume-weight determination was made on a part of the mortar. The mortar was then replaced in the mixing bowl and remixed for 15 sec., after which the 2-in. cube specimens were made. The cube molds were filled in two layers by rather forcibly projecting the mortar into the mold by means of a $\frac{1}{4}$-cup measuring scoop. Each layer was tamped, using just sufficient pressure to insure uniform filling of the molds as specified in Method C 109 - 44.

Compressive strength specimens were made of each of the mortars C and D for each of the cements. Three specimens were tested in compression at each of the ages of 3, 7, and 28 days and three specimens were stored for testing at a later age.

Air Content Determinations:

Tests on Mortars A, B, C, and D.—Determinations were made of the air contents of mortars A, B, C, and D made for the strength test specimens and also on mortars E and F and pastes L and H which will be described later.

After the flow determinations were made, each of the mortars A and B were replaced on the mixing slab and remixed for about 10 sec., after which the volume-weight or bulk-specific-gravity determinations were made.

For mortars C and D, volume-weight determinations were made immediately after mixing.

Bulk-specific-gravity or volume-weight determinations were made as follows:

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[10] 1943 Supplement to Book of A.S.T.M. Standards, Part II, p. 79.

[11] 1942 Book of A.S.T.M. Standards, Part II, p. 1055.

[12] 1944 Book of A.S.T.M. Standards, Part II, p. 1203.

A 210-ml. brass cup, 2.5 in. in diameter and 2.5 in. high, was placed on a small platform vibrator and filled in 3 to 5 layers as the cup was vibrated. (Some preliminary studies of different methods of placing the mortars in the cup indicated the desirability of the use of a vibrator from the standpoint of reproducibility and ease of placement of the dry mixes). The drier, less plastic mortars were placed in the cup in the smaller amounts. A quantity of the mortar was placed in the center of the cup and the vibrator started. Succeeding quantities were placed in the cup as soon as the preceding amount had been leveled. The time required to fill the cup to overflowing varied from 15 sec. to 1 min., depending on the placeability of the mortar. Care was taken not to overvibrate and cause loss of entrained air. Excess mortar was struck off with a sawing motion of a straightedge, and the cup and contents were weighed to the nearest 0.1 g. Tests were made on two batches of each type of mortar for each water content of each of the cements. If the calculated air contents of the pairs of mortars differed by more than 1 per cent, additional tests were made.

Mortar E.—Mortar E, 1:3 by weight cement to standard 20–30 Ottawa sand, was used in the test as proposed by Kennedy (3) as a performance test. One hundred grams of cement were mixed for 30 sec. with 60 ml. of water in a 400-ml. beaker. Three-hundred grams of sand were then added and mixed for 2 min. with a spatula. A 206-ml. brass cup, 2.0 in. in diameter and 4.0 in. tall, was filled with the mortar in three layers, jiggling the container after each addition. The excess mortar was struck off with a straightedge and the cup and contents were weighed to 0.1 g. Duplicate determinations of entrained air were made for each of the cements.

Mortar F.—Mortar F, 1:4 by weight cement to standard 20–30 Ottawa sand, was mixed in accordance with the methods prescribed in the A.S.T.M. Tentative Method of Test for Air Content of Portland-Cement Mortar (C 185 – 44 T),[13] except that the batch size differed from that specified in the tentative method, 250 g. of cement and 1000 g. of sand being used. The mortar was mixed vigorously as specified. The Burmister flow trough used in determining the consistency was made of brass and had a ¼-in. strip across the top of the open end of the trough to maintain its rigidity.

In determining the air entrained in the 1:4 mortar, the 210-ml. cup and vibrator were used in the same manner as described above for mortars A, B, C, and D. Air determinations were made simultaneously with the flow determination. Duplicate tests were made for each of the cements, using a new batch for each determination.

A supplemental series of air determinations was made on 15 of the cements using the 1:4 mortar. In these tests there were used: (1) the 210-ml. cup and vibrator as described above, (2) a 206-ml. cup in which the mortar was compacted by jiggling the cup, and (3) a 500-ml. cup using the method of filling specified in Tentative Method in C 185 – 44 T. The batch was larger (400 g. cement, 1600 g. sand) so that all three cups could be filled simultaneously from the same batch of mortar. Some additional tests were also made to determine the relation of the flow obtained on the flow table to flow obtained by use of the Burmister trough. The flow on the flow table was obtained in the usual manner except that the percentage increase in diameter of the mortar was determined after ten ½-in. drops.

Pastes L.—A motor-driven mixing

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[13] 1944 Book of A.S.T.M. Standards, Part II, p. 1227.

device was used in the preparation of the pastes L. The mixing mechanism consisted of a rubber paddle $3\frac{3}{8}$ in. long, $1\frac{1}{8}$ in. wide, and $\frac{1}{8}$ in. thick which was rotated about its longitudinal vertical axis at 350 rpm. In the preparation of the paste, 400 g. of cement was added to 200 ml. of water and mixed in a 4-in. diameter mixing cup for 2 min. During the mixing procedure, the cup was moved about in such a manner that the sides and bottom were scraped by the revolving paddle. After being mixed, the paste was poured into the 206-ml. cup described above. The cup was filled to overflowing and the excess paste removed by sliding a small glass plate onto the container. This tended to remove the large bubbles of air at the top of the paste. The container and contents were weighed to the nearest 0.1 g. Duplicate determinations of entrained air were made for each of the cements.

Pastes H.—The pastes H were mixed in a 2-cup size cocktail type food mixer. This type of mixer was used in an attempt to incorporate as much air in the paste as possible. In the preparation of the paste H, 270 g. of cement and 135 g. of water were placed in the mixer and were shaken for 1 min., let stand for 1 min., and then reshaken for $\frac{1}{2}$ min. The paste was then poured into the 206-ml. cup described above. The excess paste was removed by means of the glass plate and the container with contents weighed to the nearest 0.1 g. Duplicate determinations using this method were made for each of the cements.

Concrete.—The concrete contained 1 part cement, 2.2 parts sand, and 3.3 parts gravel by weight. Enough water was added to secure a slump of 3 ± 1 in. A batch of concrete slightly greater than $\frac{1}{2}$ cu. ft. was mixed 5 min. in a 0.6-cu. ft. Lancaster mixer. The weight per cubic foot was determined according to the method prescribed in A.S.T.M. Standard Method of Test for Yield of Concrete (C 138 – 39)[14] using a $\frac{1}{2}$-cu. ft. container. The fineness modulus of the sand was 3.02; the fineness modulus of the sand plus aggregate was 4.87. The maximum size of the aggregate was 1 in. Dry sand and aggregate were used in making the concrete.

Approximately 10 min. were required from the start of mixing to the completion of the concrete weight determination. Because of this, the apparent specific gravity of the coarse aggregate was calculated from the weight of the aggregates as used and the weight in water after 10 min. soaking. The apparent specific gravity of the concrete sand was also determined after 10 min. soaking.

Only one weight-per-cubic-foot determination was made with each of the cements except with one cement for which seven weight determinations were made on different batches made on four different days to obtain an idea of the precision of the test results.

Calculation of Air Contents:

The air contents of the mortars, pastes, and concrete were calculated by the following formula:

$$\text{Air, per cent} = 100\left(1 - \frac{W_o}{W_c}\right)$$

where:

W_o = observed weight per unit volume, and

W_c = calculated or theoretical weight per unit volume.

The observed weight per unit volume (W_o) was computed by dividing the net weight of the mortar, paste, or concrete in the measuring cup by the volume of the cup used.

The calculated or theoretical weight

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[14] 1942 Book of A.S.T.M. Standards, Part II, p. 408.

per unit volume (W_c) is the summation of weights of the batched materials divided by the summation of the absolute volumes of these same materials. The volumes of entering materials were computed using a specific gravity of 3.15 for cement, 2.65 for Ottawa sand, and 2.62 as the average for the fine and coarse aggregates after 10 min. soaking.

The use of this general formula resulted in the same calculated air content values as would be obtained by the use of the formula in Method C 185 - 44 T which applies only to 1:4 mortar.

RESULTS OF THE TESTS

The results of the tests are presented in detail in Tables I and III.

Vinsol Resin Content of Cements:

It may be noted from Table I that the chloroform-soluble material of the commercial Vinsol resin cements varied from 0.007 to 0.123 per cent. Twenty of the 64 Vinsol resin cements had quantities of chloroform-soluble material either greater or less than the limits of 0.025 to 0.045 per cent specified by Federal Specification SS - C - 191b, amendment 1, and which were also the limits in the recently revised A.S.T.M. Specifications C 175 - 42 T. The amount of Vinsol resin was determined by the methoxyl method on 13 of the cements and was generally in fair agreement with the amount determined by the chloroform-soluble method but in most cases the Vinsol resin values obtained by the methoxyl method were slightly lower than those obtained by the chloroform-soluble method.

Fineness:

Turbidimeter fineness tests indicated that 6 of the 64 Vinsol resin cements had a specific surface of 2000 sq. cm. per g. or greater. The ratio of air permeability to turbidimeter fineness values varied from 1.6 to 2.1. There was no definite relation between fineness, as determined by either the turbidimeter or the air-permeability method, and the other determined properties of the Vinsol resin cements.

Normal Consistency of Neat Pastes:

The percentage of water required to produce a paste of normal consistency varied over a wide range for the different cements. The distribution of values is indicated in Fig. 1.

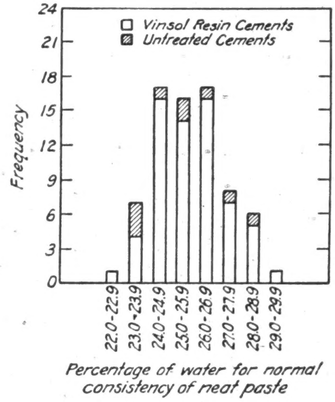

FIG. 1.—Frequency Distribution of Percentage of Water Required for Normal Consistency of Neat Pastes of Vinsol Resin and Untreated Cements.

The check determinations, by the same or by different operators were in close agreement with each other.

One of the characteristics of the Vinsol resin neat pastes was a quick stiffening tendency. This property of quick stiffening is also encountered to a lesser degree with some portland cements, most high-early-strength cements, and with masonry cements. In order to obtain a penetration of 10 mm. in the normal consistency determination, more water was added to a majority of the Vinsol resin cements than would ordinarily be necessary for untreated type I or II cements. The Vinsol resin neat pastes were, in most cases, very workable and sticky during the mixing operation and in one instance almost liquid. Because of the stickiness, it was impossible with many of the cements to knead the pastes vigorously, and impossible to form into a ball and toss the paste from the one hand to the other as specified. The time elapsing between the completion of the filling of the Vicat ring and the release of the plunger was a particularly important factor affecting the depth of penetration in the normal consistency determination of Vinsol resin cements.

In some additional tests, a few of the cement pastes were mixed the required time, allowed to stand about 2 min., and then reworked. This usually resulted in a greater penetration than was obtained when the standard normal consistency procedure was used, because the cement pastes did not stiffen so rapidly after the reworking. It might, therefore, be desirable to specify a waiting period and then a reworking of the paste before the penetration test of the normal consistency determination. Such a procedure could be used for other types of cements as well.

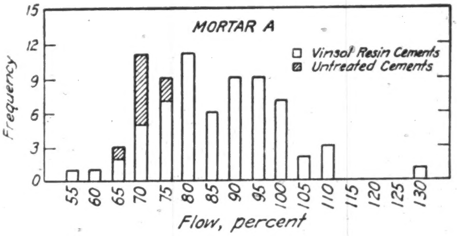

Fig. 2.—Frequency Distribution of Percentage of Flow of 1:3 Mortars of the Different Cements when the Amount of Mixing Water Was Based on the Water Requirement of the Neat Paste of Normal Consistency of the Respective Cements.

The flow values are presented to the nearest 5 per cent.

Flow:

Mortars A and B.—When the percentage of water for the 1:3 mortars was based on the water requirements of the neat pastes of the Vinsol resin cements, the resulting mortar A had flows ranging from 57 to 128 per cent. The distribution of flow values of all the cements is presented in Fig. 2.

It may be noted from this figure that although most of the Vinsol resin cements when tested in mortar A had flow values above the 65 to 75 range found for the untreated cements, 14 had flows in this same range, and 2 had lower flow values. These two last cements therefore required more water in mortar B than in mortar A. It may be noted that the three untreated high-early-strength cements were in the group having a flow of 65 to 75 per cent for mortar A. Histograms showing the water requirements of mortars A and B are presented in Fig. 3.

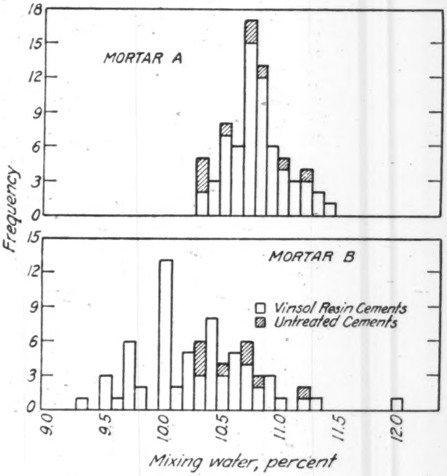

Fig. 3.—Frequency Distribution of Percentage Water Requirements of 1:3 Tension Test Mortars.

In mortar A the amount of water was based on water requirements of the neat pastes of normal consistency, whereas the B mortars were gaged with enough water to have a flow of 70 ± 5 per cent.

The range of water requirements for mortar B was found greater than for mortar A. The water requirements of mortar A ranged from 10.3 to 11.4 per cent for the different cements whereas mortar B required from 9.3 to 12.0 per

TABLE I.—VINSOL RESIN CONTENT, FINENESS, CONSISTENCY AND STRENGTH

Cement	Cement Type[a]	Grinding Circuit[b]	Vinsol Resin, per cent		Fineness, sq. cm. per g.		Porosity, Air-Permeability Test	Water Requirements				Flow, per cent				Tensile Strength, psi.						Compressive Strength, psi.						Cement
																Mortar A			Mortar B			Mortar C			Mortar D			
			Chlor. Sol. Method	Methoxyl Method	Turbidimeter	Air Permeability		Normal Consistency, Neat Paste, per cent water	Mortar A, per cent	Mortar B, per cent	Mortar D, water-cement ratio	Mortar A	Mortar B	Mortar C	Mortar D	3 Day	7 Day	28 Day	3 Day	7 Day	28 Day	3 Day	7 Day	28 Day	3 Day	7 Day	28 Day	
No. 1	I	O	0.028		2050	3650	0.481	25.6	10.8	9.5	0.46	112	72	150[c]	104	275	400	410	400	465	485	1720	2670	3830	2140	3190	4300	No. 1
No. 2	II	O	0.029		1870	3310	0.448	23.4	10.4	9.3	0.46	106	64	150[d]	105	240	315	365	320	400	440	890	1560	3540	1170	1920	3790	No. 2
No. 3	I	O	0.031		1740	3710	0.481	26.0	10.8	10.0	0.49	100	70	128	104	285	345	420	305	370	425	1500	2420	3340	1700	2510	3440	No. 3
No. 4	II	O	0.025		1560	3070	0.465	24.0	10.5	9.7	0.49	98	65	127	104	205	250	425	245	320	445	900	1360	2090	1000	1500	2130	No. 4
No. 5	I	C	0.033		1600	3120	0.481	24.6	10.6	10.0	0.47	98	67	150[c]	100	235	320	415	315	360	455	920	1250	3210	1260	1400	3410	No. 5
No. 6	I	C	0.038		1520	2990	0.481	27.0	11.0	10.3	0.47	109	76	148	105	270	340	405	335	390	410	1120	1940	3220	1650	2710	3790	No. 6
No. 7	II	C	0.028	0.025	1790	2910	0.481	25.0	10.7	9.5	0.47	105	65	142	109	245	285	360	280	390	460	930	1190	2240	1090	1450	2340	No. 7
No. 8	I	O	0.040		1600	3040	0.481	24.5	10.6	10.0	0.49	97	65	135	106	340	400	450	350	405	465	1500	2440	3910	1640	2620	4090	No. 8
No. 9	I	O	0.031		1730	3200	0.481	24.5	10.6	10.6	0.50	64	64	131	102	285	360	480	285	360	480	970	1600	2540	1130	1700	2760	No. 9
No. 10	II	O	0.027		2010	3660	0.498	27.4	11.1	10.6	0.50	84	69	124	103	280	375	440	300	420	485	1440	2540	4130	1610	2700	4280	No. 10
No. 11	I	O	0.033	0.027	1590	3100	0.481	23.0	10.3	9.7	0.48	94	66	147	106	290	355	420	355	405	455	1020	2000	3080	1210	2190	3420	No. 11
No. 12	II	O	0.027		1740	3060	0.465	22.8	10.3	10.3	0.50	78	78	133	104	260	360	455	260	360	455	1120	1440	2380	1160	1540	2530	No. 12
No. 13	I & II	O	0.028		2220	4340	0.481	24.0	10.5	10.5	0.50	68	68	132	114	310	445	485	310	445	485	1830	2920	3590	2040	2970	4080	No. 13
No. 14	I	C	0.026		1920	3370	0.481	24.6	10.6	10.6	0.50	73	73	132	110	385	445	475	385	445	475	1740	2920	4870	1850	3130	4900	No. 14
No. 15	I & II	C	0.031	0.026	1820	3010	0.481	23.4	10.4	9.7	0.46	98	68	136	98	280	315	435	310	440	450	1240	2080	3560	1390	2240	3890	No. 15
No. 16	I	O	0.030		1930	3650	0.481	26.4	10.9	10.5	0.51	78	63	124	112	340	390	430	350	430	500	1630	2630	4180	1750	2900	4360	No. 16
No. 17	II		0.024	0.020	1840	3020	0.465	25.0	10.7	10.7	0.50	73	73	125	102	245	290	475	245	290	475	990	1560	3190	1010	1650	3280	No. 17
No. 18	II	O	0.023		1970	4080	0.481	28.4	11.2	10.7	0.51	81	66	120	108	335	385	465	390	400	495	2020	3030	4710	2140	3490	5010	No. 18
No. 19	II	O	0.019		1900	3830	0.481	26.6	10.9	11.2	0.51	57	66	122	109	385	400	485	370	375	420	1980	3420	4620	2190	3480	5070	No. 19
No. 20		C	0.044		1720	3030	0.481	26.0	10.8	10.8	0.50	76	76	128	105	255	295	440	255	295	440	980	1400	3120	1070	1650	3310	No. 20
No. 21	II		0.027		1890	3380	0.481	24.0	10.5	9.6	0.46	128	68	148	104	290	365	415	325	425	540	1220	1890	3440	1600	2440	4200	No. 21
No. 22		C	0.045		1780	3210	0.498	28.8	11.3	11.3	0.51	76	76	120	105	330	395	440	330	395	440	1730	2170	4150	1730	2250	4230	No. 22
No. 23	I	C	0.027		1730	2970	0.481	24.9	10.6	10.0	0.49	84	68	136	108	210	300	415	290	415	450	1240	2210	4260	1410	2430	4600	No. 23
No. 24	I	C	0.020		1940	3370	0.481	27.2	11.0	10.3	0.50	86	66	127	106	260	410	425	340	430	505	1520	2680	4130	1710	2780	4710	No. 24
No. 25	II		0.031		1870	3830	0.481	26.4	10.9	10.9	0.50	70	70	136	112	250	340	440	250	340	440	1180	1720	2880	1270	1790	3180	No. 25
No. 26	I	C	0.052		1650	3400	0.481	25.0	10.7	10.0	0.49	92	70	138	110	265	350	450	345	380	470	1390	2270	4010	1600	2590	4080	No. 26
No. 27	I	O	0.025	0.024	1730	3340	0.515	26.2	10.8	10.6	0.50	78	62	130	107	320	430	515	390	450	535	1740	2920	4710	2030	3210	4870	No. 27
No. 28	I	O	0.038		1980	4140	0.481	26.6	10.9	10.9	0.50	76	76	131	112	315	370	435	315	370	435	1510	2500	4370	1700	2760	4620	No. 28
No. 29	I	C	0.025		1850	3120	0.481	25.2	10.7	10.2	0.48	86	68	139	107	250	310	385	285	350	395	1270	2400	3870	1590	2700	4530	No. 29
No. 30	I	C	0.029		1690	3050	0.481	25.0	10.7	9.7	0.48	94	66	142	106	285	335	385	350	405	495	1350	2340	3750	1580	2520	3880	No. 30
No. 31	I	C + O	0.016		1790	3340	0.481	24.2	10.5	10.2	0.49	81	71	138	114	250	335	455	300	345	470	1210	2120	3570	1370	2200	3720	No. 31
No. 32	I	C	0.016		1690	3020	0.481	24.0	10.5	10.2	0.48	78	68	138	101	350	365	395	365	385	460	1520	2510	4070	1710	2750	4610	No. 32
No. 33	II		0.042		1810	3340	0.481	26.4	10.9	10.9	0.50	74	74	133	112	260	335	420	260	335	420	1070	1490	2510	1210	1620	2900	No. 33
No. 34	I	C	0.038		1730	3510	0.481	24.8	10.7	10.0	0.49	94	69	135	111	230	320	385	290	355	460	1180	1870	3720	1410	2040	3930	No. 34
No. 35		C	0.007	0.009	2420	4560	0.532	28.8	11.3	12.0	0.50	58	74	133	108	465	530	565	440	480	550	3360	4620	6260	3740	5330	6610	No. 35

No. 36	I	O	0.024	0.019	1850	3500	0.481	25.0	10.7	10.0	0.50	91	74	132	113	250	340	460	335	410	480	1370	2290	4040	1500	2440	4300	No. 36
No. 37	I	C	0.043	0.043	1630	2800	0.481	25.0	10.7	9.8	0.48	92	70	137	107	240	335	425	295	395	460	1190	2180	3380	1280	2380	3770	No. 37
No. 38	II	C	0.033		1740	3070	0.481	26.0	10.8	9.7	0.48	98	64	140	103	240	295	405	295	365	460	1040	1580	3210	1300	1670	3980	No. 38
No. 39	I	C	0.026		1740	3280	0.481	26.0	10.8	9.5	0.50	80	71	127	104	250	390	460	305	405	485	1420	2610	3950	1510	2660	4190	No. 39
No. 40	I	C	0.027		1630	2980	0.481	27.6	11.1	10.4	0.50	94	75	128	106	195	295	380	245	360	455	980	1930	3520	1130	2000	3730	No. 40
No. 41	II	C	0.023		1930	3170	0.481	29.4	11.4	10.5	0.49	91	62	134	103	210	285	440	250	370	470	1140	1650	3120	1280	1960	3780	No. 41
No. 42	I	C	0.026		1750	3430	0.481	26.0	10.8	10.8	0.50	73	73	133	112	275	390	435	275	390	435	1460	2380	3790	1520	2680	4070	No. 42
No. 43	I	O	0.032		2090	3910	0.481	26.0	10.8	10.4	0.49	84	71	132	108	310	380	430	320	405	475	1650	2860	4080	1910	3030	4770	No. 43
No. 44	I	C	0.036		1850	3190	0.481	25.0	10.7	10.1	0.48	88	70	138	103	275	340	415	310	375	485	1290	2360	4020	1440	2620	4130	No. 44
No. 45	I	C	0.030	0.026	1530	2690	0.481	25.4	10.7	10.7	0.50	72	72	129	109	325	370	440	325	370	440	1400	2520	3880	1560	2830	4070	No. 45
No. 46	I	C	0.011		1640	3180	0.481	23.6	10.4	10.4	0.50	68	68	133	111	275	360	490	275	360	490	1320	2090	3900	1480	2620	4130	No. 46
No. 47	I	C	0.020	0.019	1700	3100	0.515	27.0	11.0	10.4	0.50	89	70	128	108	275	390	480	350	445	495	1360	2220	4440	1390	2550	4680	No. 47
No. 48	I	C	0.027		1780	3320	0.481	25.0	10.7	10.7	0.49	71	71	130	101	300	375	425	300	375	425	1340	2130	3590	1700	2430	4410	No. 48
No. 49	I	C	0.026		1750	3060	0.481	24.0	10.6	10.0	0.49	82	69	137	109	250	350	500	285	375	505	1120	1950	3520	1370	2010	3750	No. 49
No. 50	I	C	0.023		1740	3090	0.481	25.0	10.7	10.0	0.48	95	70	140	104	280	345	425	330	430	480	1510	2550	4490	1640	3080	5130	No. 50
No. 51	II	C	0.040		1680	3220	0.481	24.8	10.7	10.0	0.49	91	71	137	105	275	320	405	305	400	430	1380	1920	2780	1450	2010	2900	No. 51
No. 52	I	C	0.036		1930	3550	0.481	25.6	10.8	10.1	0.48	89	70	141	103	305	425	440	355	445	475	1830	2320	4630	2080	3430	5010	No. 52
No. 53	II	O	0.021		1950	3400	0.498	27.0	11.0	10.2	0.49	101	72	138	111	290	340	450	330	410	480	1230	1690	3060	1550	2200	3620	No. 53
No. 54	I	C	0.029	0.028	1760	3360	0.515	28.0	11.2	10.4	0.50	96	74	131	111	260	330	385	335	390	470	1520	2500	4040	1680	2760	4340	No. 54
No. 55	I	C	0.032		1700	3060	0.481	25.0	10.7	10.4	0.50	78	69	130	109	320	385	490	340	495	505	1820	3480	5030	1970	3620	5410	No. 55
No. 56	II	O	0.038		1970	3400	0.481	26.0	10.8	10.4	0.49	81	67	131	104	270	345	450	305	405	500	1670	2210	3500	1840	2330	3630	No. 56
No. 57	I	C	0.025		1770	2930	0.481	26.0	10.8	9.8	0.47	102	71	144	108	270	340	410	310	395	480	1240	1780	3150	1390	1920	3230	No. 57
No. 58			0.123	0.129	2280	4370	0.498	27.6	11.1	9.7	0.46	112	67	150[d]	101	240	320	365	355	385	465	1450	2120	2930	1700	2360	3440	No. 58
No. 59	II	C + O	0.022		1640	2940	0.481	26.4	10.9	10.0	0.48	95	74	136	105	295	330	405	330	360	420	1070	1500	2140	1170	1710	2590	No. 59
No. 60	I	C	0.040		1890	3370	0.481	24.4	10.6	10.0	0.49	90	74	131	107	280	355	425	360	370	445	1480	2330	4120	1740	2570	4290	No. 60
No. 62	I	C	0.034		2000	3590	0.481	26.0	10.8	10.6	0.49	80	70	133	106	250	360	525	320	455	545	1620	2580	4360	1920	3340	5330	No. 62
No. 63	I	C	0.022		1580	3080	0.481	24.0	10.5	10.0	0.50	86	71	130	111	270	345	435	335	380	455	1370	2150	3640	1540	2360	3790	No. 63
No. 64	I	O	0.021		1960	3460	0.481	28.6	11.2	10.2	0.50	93	64	133	114	280	350	405	340	375	460	1450	2220	3280	1610	2260	4020	No. 64
No. 65	I	C	0.017	0.013	1700	3440	0.481	24.0	10.5	10.5	0.49	64	64	136	100	330	420	555	330	420	555	1720	2440	3640	2100	3110	4560	No. 65
No. 61[e]			0.001		1790	3170	0.481	25.4	10.7		0.51	70		121														No. 61
No. 66[e]	I		0.001		1720	3250	0.481	25.0	10.7		0.50	66		133														No. 66
No. 67[e]	III		0.007		2540	5140	0.515	26.0	10.8		0.50	70		128														No. 67
No. 68[e]	I		0.000		1810	3230	0.481	24.0	10.5		0.50	68		130														No. 68
No. 69[e]	I		0.004		1620	3200	0.481	23.0	10.3		0.50	70		129														No. 69
No. 70[e]	III		0.004		2710	5420	0.515	28.4	11.2		0.50	**74**		121														No. 70
No. 71[e]	I		0.003		1710	3050	0.481	23.0	10.3		0.50	**70**		127														No. 71
No. 72[e]	III		0.000		2810	5290	0.515	27.2	11.0		0.50	74		125														No. 72
No. 73[e]			0.000		1600	3010	0.465	23.0	10.3		0.51	68		123														No. 73

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[a] Indicated by producer.
[b] O = open circuit, C = closed circuit.
[c] In 22 drops.
[d] In 23 drops.
[e] Furnished as untreated cements.

cent water. The operators considered that mortars B made of the Vinsol resin cements to a flow of 70 ± 5 per cent were similar in their mixing and molding properties to the normal consistency mortars made of the untreated cements. Certain of the Vinsol resin cements, however, had a tendency to stiffen rather rapidly, making the time element an important factor in the proper fabrication of the tension test specimens. It might, therefore, be desirable, just as with the neat pastes, to require a waiting period and then a reworking of the mortars before making flow measurements and molding strength test specimens.

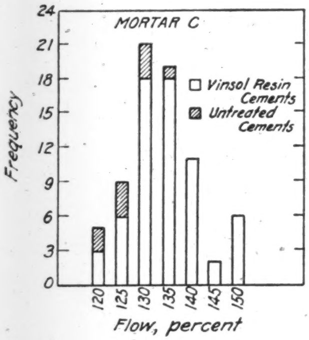

FIG. 4.—Frequency Distribution of Percentage of Flow of 1:2.75 Mortars of the Different Cements for a Water Cement Ratio of 0.53.

The flow values are presented to the nearest 5 per cent.

Mortar C.—Mortar C was prepared in accordance with Tentative Method C 109 - 43 T using a constant water-cement ratio (53 per cent by weight of cement).

As may be noted in Table I, the flows for the mortars C made with the untreated cements ranged only from 120 to 135 per cent. However, the C mortars made from the Vinsol resin cements had flows ranging from 120 to over 150 per cent, a few being so fluid that they exceeded the capacity of the flow table in the specification test and attained a flow of 150 per cent in only 22 drops.

It might also be noted that some of the Vinsol resin cements had lower flow values than were obtained with some of the cements not containing Vinsol resin. Of the untreated cements, the high-early-strength cements had about the same flows as the other untreated cements in mortar C. Figure 4 indicates the distribution of flows of the C mortars.

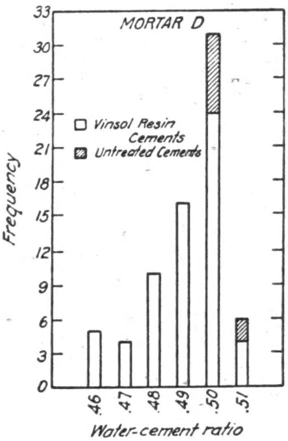

FIG. 5.—Frequency Distribution of Water-Cement Ratios of the 1:2.75 Plastic Mortars of the Different Cements when Gaged with the Amount of Water Needed for a Flow of 100 to 115 per cent.

Mortar D.—All of the cements required less water for mortar D (100 to 115 flow) than was required in the corresponding C mortar (53 per cent water by weight of cement). Figure 5 indicates the distribution of water requirements of the D mortars.

Reproducibility of Flows.—The flow values determined on the duplicate pairs of mortar batches were in close agreement in most instances. In an analysis of the flows of 200 pairs of mortar batches from the A, B, C, and D mixes it was found that the difference in flows of the pairs of mortars was 1 or less for 34 per cent of the mortars, 2 or less for 57 per cent,

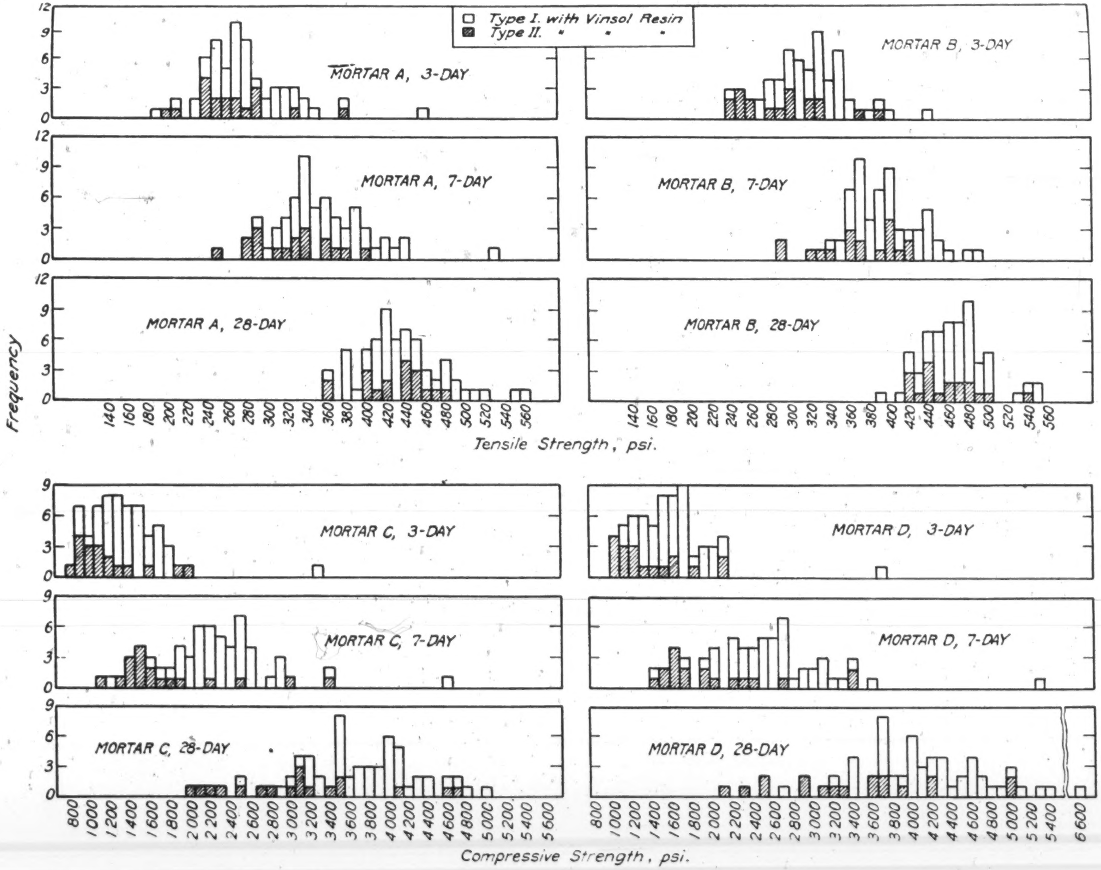

FIG. 6.—Frequency Distribution of 3, 7, and 28-day Tensile and Compressive Strengths of the 64 Vinsol Resin Cements, when Proportioned by Different Methods.

Strengths of the cements of each group range from the value of the group to the value of the next higher group.

3 or less for 76 per cent, 4 or less for 88 per cent, 5 or less for 95 per cent, and 10 or less for 100 per cent of the mortars. These differences in flow may be partly due to slight variations in mixing technique which may affect the air content of the mortar, and partly due to lack of uniformity in placement of the mortar in the flow cone. However, these differences in flows were smaller than are commonly obtained on different flow tables in different laboratories.

Strength:

In the presentation of the strength data, the cements were designated according to the types as reported by the manufacturers. However, all the cements were considered together because some of the cements were made to meet the specification requirements of both types I and II.

The 3, 7, and 28-day strengths of mortar specimens made of mortars A, B, C, and D are presented in Fig. 6.

Most of the cements of both types I and II had strengths greatly in excess of their respective specification requirements for air-entraining cements. For example, for mortar A, which has been criticized as having too much water for satisfactory placement, almost half of the Vinsol resin cements met the type Ia, 7-day tensile strength requirement prevailing at the time of these tests[15] in 3 days and three met the 28-day requirement in 3 days. Only one of these three was of very high fineness; the other two, although above average, had specific surface values of less than 2000 sq. cm. per g. by the turbidimeter method. At 7 days, half of the cements had attained the type Ia 28-day strength requirement of the specification. At 28 days all cements met the specification requirements and about one-third of the cements had a tensile strength of 100 psi. or more above that required for type Ia in the specification.

The tensile strength of the mortar B specimens was greater than that of the mortar A specimens made of the same cement for those cases where less water was used for the corresponding mortar B. With some cements, a slight decrease in water caused a greater increase in strength than did a larger decrease in water with other cements (see Table I).

Specimens made of the C mortars of the various cements had 3-day compressive strengths above the specification requirements. Most of the cements had compressive strengths at all ages far above those required by the specifications.

TABLE II.—STRENGTHS OF THE MORTARS-GRAND AVERAGES FOR ALL CEMENTS AND VARIATIONS OF INDIVIDUAL CEMENTS FROM THE AVERAGES.

Age, Days	Mortar A		Mortar B		Mortar C		Mortar D	
	Strength, psi.	Coefficient of Variation	Strength, psi.	Coefficient of Variation	Strength, psi.	Coefficient of Variation	Strength, psi.	Coefficient of Variation
3.....	280	14	315	12	1360	21	1550	20
7.....	355	11	390	10	2190	22	2440	22
28.....	435	9	465	7	3650	18	3990	18

The relative strengths of the mortars C and D are of interest inasmuch as they represent the strengths of the cements as tested by the former and by the revised Tentative Specifications C 175[12].

In practically all cases the specimens made of mortar D had greater compressive strengths at all ages than the respective mortar C made of the same cements, and in no case was the strength of the mortar D less than that of the corresponding mortar C. As was the case with the tension tests, the relation between the increase in compressive strength and the decrease in amount of mixing water was not the same for all cements. The difference between the 7-day compressive strengths of the mortars C and D of the respective cements ranged from 40 to 770 psi., but it may be noted that the compressive strengths of the D mortars of the different Vinsol resin cements ranged from 1400 to 5330 psi.

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[15] Reference is made to tensile strength requirements in A.S.T.M. Specifications C 175 - 42 T, EA C 150, and Federal Specification SS - C - 191b.

An analysis of the distribution or scatter of the strength data in Table I is presented in Table II. The strengths of all of the cements (except No. 35) were averaged for each test age for each of the mortars A, B, C, and D. The variations of the strengths of the different cements from the grand averages were determined by calculating the coefficient of variation (**4**). The coefficient of variation as used in this study has no relation to the reproducibility of results of tests of any one of the mortars of any one cement but concerns the strengths found for the different cements. A small coefficient of variation indicates that there was little difference in the strength of the different cements; conversely, a large coefficient of variation indicates large differences in strengths of the different cements. The average strengths and the coefficients of variation are presented in Table II.

It may be noted from this table that the coefficients of variation of compressive strengths (mortars C and D) of the different cements were about twice as great as the coefficients of variation of the tensile strengths (mortars A and B) of the different cements, or, in other words, the dispersion in strength of the different cements was twice as great when determined by the compression test as when determined by the tension test. The percentage dispersion decreased with age in mortars A and B, whereas no significant trend with age was noted for mortars C and D. Mortar B, designed for constant flow, had a slightly smaller percentage dispersion for the different cements than mortar A at all ages. Mortars C and D although gaged with different amounts of mixing water had approximately the same strength dispersion at all ages.

Entrained Air:

In Table III are presented the calculated air contents of the various pastes, mortars, and concrete together with the water-cement ratios of the 1:4 mortar and of the concrete.

Pastes.—In general, there was little difference in the air contents of the L pastes made of the different cements. Seven out of nine of the pastes made of cements without Vinsol resin together with nine Vinsol resin cements had air contents of less than 1 per cent. Forty seven of the Vinsol resin cements had air contents of between 1 and 3 per cent and eight of the Vinsol resin cements had air contents above 3 per cent.

The majority of the H pastes made of Vinsol resin cements had from one third to approximately the same percentage of air as the concrete made from the corresponding cements. A number of these cement pastes had bulk-specific-gravity values slightly greater than the theoretical, resulting in calculated air contents less than zero.

Mortars A and B.—The relations of the air contents of mortars A and B to the air content of the concrete made of the same cements are presented in Figs. 7 and 8.

It may be noted from these figures that although there is a general trend of increase in air content of the concrete with increase in air content of mortars A and B made of the respective cements, the scattering is very great. The A mortars made of the cements not containing Vinsol resin had air contents of from 9.5 to 12.5 per cent, whereas those made of Vinsol resin cements had air contents of 9 to 17 per cent with most

TABLE III.—AIR CONTENTS OF PASTES, MORTARS, AND CONCRETE.

Cement	Air Content, per cent									Water Cement Ratio by Weight	
	Paste H	Paste L	Mortar A	Mortar B	Mortar C	Mortar D	Mortar E	Mortar F	Concrete	Mortar F	Concrete
No. 1	6.5	4.9	14.9	14.7	12.5	14.0	14.2	17.9	7.8	0.60	0.53
No. 2	8.3	3.4	15.3	13.3	12.6	14.0	10.4	17.5	8.4	0.60	0.51
No. 3	3.8	3.9	15.3	15.0	13.7	14.1	14.3	17.7	8.7	0.64	0.55
No. 4	5.6	1.9	14.4	12.6	11.8	12.3	19.9	15.4	6.4	0.64	0.53
No. 5	3.8	1.6	13.4	13.0	10.3	11.3	9.5	9.8	5.0	0.72	0.54
No. 6	9.5	4.1	14.8	14.2	16.2	15.2	12.6	23.2	13.0	0.58	0.50
No. 7	11.4	0.5	16.0	14.2	14.9	15.8	10.7	23.1	14.8	0.56	0.52
No. 8	3.4	1.6	13.3	13.6	11.5	12.9	10.7	13.5	5.5	0.68	0.52
No. 9	2.0	1.1	12.0	12.0	9.6	10.1	9.3	10.0	5.6	0.72	0.52
No. 10	1.5	2.3	13.2	11.7	10.2	11.2	7.8	9.2	4.2	0.76	0.56
No. 11	3.9	2.0	15.1	13.5	12.6	13.8	11.8	17.1	8.4	0.64	0.52
No. 12	2.8	1.2	12.2	12.2	11.8	12.7	9.9	13.7	7.5	0.68	0.51
No. 13	3.8	2.2	12.1	12.1	9.8	11.8	6.0	10.7	4.1	0.72	0.54
No. 14	2.4	1.5	13.2	13.2	11.5	11.8	7.0	13.1	5.8	0.68	0.55
No. 15	2.8	3.7	13.8	12.7	14.9	11.7	9.2	10.4	5.3	0.72	0.51
No. 16	2.9	1.5	13.4	13.0	10.8	12.1	7.6	13.3	5.7	0.70	0.53
No. 17	1.3	0.5	12.3	12.3	9.9	10.2	6.0	9.9	3.9	0.70	0.53
No. 18	6.3	3.5	13.6	12.7	12.4	12.5	9.2	12.8	8.0	0.72	0.54
No. 19	5.8	3.6	10.7	12.2	11.2	11.8	9.8	11.5	7.5	0.76	0.54
No. 20	3.4	1.6	13.0	13.0	10.5	11.1	7.3	13.4	6.3	0.68	0.51
No. 21	5.1	1.5	13.4	13.3	11.9	12.7	10.0	13.8	5.7	0.66	0.52
No. 22	2.1	1.7	12.9	12.9	11.5	12.7	5.2	14.6	6.2	0.66	0.56
No. 23	2.7	1.4	14.1	13.5	12.1	13.6	8.2	12.4	7.1	0.70	0.51
No. 24	2.9	0.7	11.0	11.3	11.2	12.0	7.0	12.2	3.4	0.72	0.51
No. 25	4.4	2.0	11.0	11.0	11.0	12.1	4.9	14.0	5.4	0.68	0.50
No. 26	7.3	2.0	14.1	12.0	12.2	13.4	6.5	16.2	6.7	0.66	0.50
No. 27	1.1	2.0	12.9	12.2	9.9	10.9	5.7	11.7	2.8	0.70	0.51
No. 28	2.2	2.7	13.5	13.5	10.5	11.6	6.5	12.9	3.2	0.70	0.51
No. 29	3.2	0.9	14.9	14.4	12.2	13.1	6.5	14.5	5.2	0.70	0.50
No. 30	5.0	1.2	15.6	14.7	12.8	14.0	6.0	17.3	8.5	0.64	0.50
No. 31	2.2	1.2	14.9	14.8	11.1	12.5	5.7	13.9	5.2	0.68	0.53
No. 32	2.1	1.1	14.1	14.0	12.0	12.3	6.0	13.3	4.2	0.68	0.54
No. 33	2.6	1.6	12.4	12.4	9.8	10.5	4.4	10.2	5.2	0.74	0.54
No. 34	4.9	2.9	16.4	15.6	12.6	14.8	6.5	18.4	8.3	0.64	0.53
No. 35	1.0	1.9	9.1	9.8	7.4	8.8	4.6	5.8	1.5	0.80	0.59
No. 36	4.4	2.5	15.2	14.9	12.8	12.8	7.9	16.4	4.7	0.64	0.53
No. 37	3.8	1.7	15.6	15.8	12.6	14.4	8.4	17.9	9.0	0.64	0.53
No. 38	3.6	1.4	14.8	12.7	11.0	12.7	5.8	15.8	4.0	0.64	0.53
No. 39	0.7	1.7	14.2	13.4	9.4	10.9	5.3	11.2	2.7	0.70	0.55
No. 40	1.2	1.5	14.0	14.2	10.8	11.8	6.0	12.8	3.9	0.68	0.53
No. 41	3.0	1.6	13.0	11.2	10.5	11.9	6.0	12.4	4.4	0.70	0.53
No. 42	4.1	2.6	13.1	13.1	12.5	12.9	7.6	15.2	6.8	0.66	0.53
No. 43	2.5	2.1	14.8	14.3	12.0	12.7	8.3	13.7	4.8	0.68	0.55
No. 44	3.0	1.3	15.2	14.0	11.9	12.9	6.8	14.0	5.2	0.68	0.53
No. 45	1.4	1.2	13.1	13.1	11.8	12.3	7.6	13.8	2.9	0.68	0.54
No. 46	1.4	1.9	13.9	13.9	11.3	11.9	6.8	12.0	3.5	0.70	0.54
No. 47	0.9	2.1	14.1	13.0	10.1	10.8	7.1	12.0	4.0	0.72	0.55
No. 48	0.5	1.2	12.6	12.6	9.1	10.6	5.8	9.1	3.2	0.76	0.54
No. 49	−0.5	1.0	13.6	12.2	8.1	9.5	3.7	9.8	2.4	0.72	0.55
No. 50	2.2	1.6	16.5	14.1	11.0	12.1	9.2	14.2	4.1	0.70	0.54
No. 51	0.8	1.0	14.9	15.5	9.8	11.4	5.7	12.9	3.2	0.70	0.54
No. 52	2.5	1.1	14.8	14.3	10.8	12.4	7.2	14.6	3.6	0.68	0.55
No. 53	2.2	2.1	14.7	14.4	11.5	12.1	7.7	14.5	5.8	0.68	0.54
No. 54	2.1	2.0	16.5	16.4	13.1	14.5	11.2	19.1	8.7	0.62	0.55
No. 55	0.3	1.4	13.7	13.8	11.1	11.8	4.6	14.3	2.9	0.68	0.54
No. 56	0.5	0.8	13.1	13.6	10.0	10.8	4.5	11.3	3.2	0.72	0.53
No. 57	3.1	2.1	15.5	15.1	13.0	14.9	7.5	17.7	8.4	0.62	0.51
No. 58	7.1	8.2	16.1	14.6	13.9	15.7	10.2	22.1	10.5	0.56	0.53
No. 59	4.3	0.7	16.2	15.6	12.8	15.0	7.8	15.8	7.2	0.66	0.51
No. 60	3.3	0.5	17.0	16.7	12.1	15.1	9.1	17.0	9.3	0.64	0.52
No. 62	0.6	1.1	13.5	13.1	10.7	11.4	6.0	10.5	2.3	0.70	0.53
No. 63	2.7	0.9	14.6	14.2	11.7	12.4	6.8	14.6	6.3	0.68	0.53
No. 64	1.6	1.9	13.6	12.3	10.5	10.9	6.2	11.0	4.5	0.72	0.54
No. 65	1.4	1.6	11.6	11.6	11.0	12.0	6.6	11.4	2.7	0.72	0.56

TABLE III—*Continued.*

Cement	Air Content, per cent									Water Cement Ratio by Weight	
	Paste H	Paste L	Mortar A	Mortar B	Mortar C	Mortar D	Mortar E	Mortar F	Concrete	Mortar F	Concrete
No. 61	−0.5	0.7	10.7	10.7	7.9	8.8	2.1	2.2	1.4	0.80	0.55
No. 66	−0.4	0.5	11.2	11.2	8.3	9.2	4.1	5.1	1.1	0.80	0.56
No. 67	0.3	1.9	11.1	11.1	6.8	7.8	3.7	5.8	1.5	0.76	0.56
No. 68	−0.3	0.4	11.4	11.4	8.1	8.8	3.6	4.9	1.3	0.80	0.55
No. 69	0.4	0.8	12.6	12.6	9.8	9.8	5.8	5.4	1.0	0.80	0.56
No. 70	0.4	2.4	11.0	11.0	7.9	9.0	5.2	6.0	1.3	0.76	0.58
No. 71	−0.5	0.4	11.4	11.4	6.9	7.7	1.5	2.3	1.1	0.82	0.55
No. 72	−0.2	0.9	9.5	9.5	5.4	6.8	2.1	4.0	1.2	0.76	0.58
No. 73	−0.5	0.1	11.5	11.5	8.2	7.3	2.5	6.4	1.4	0.80	0.55

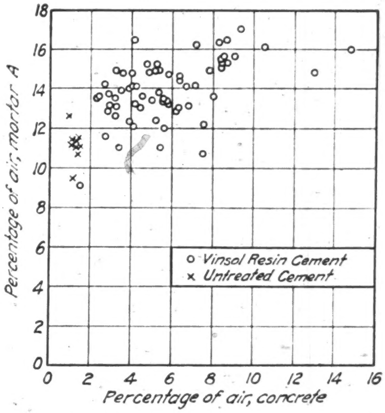

FIG. 7.—Relation of the Percentage of Air in the 1:3 Tension Test Mortar of Normal Consistency to the Percentage of Air in Concrete Made of the Respective Cements.

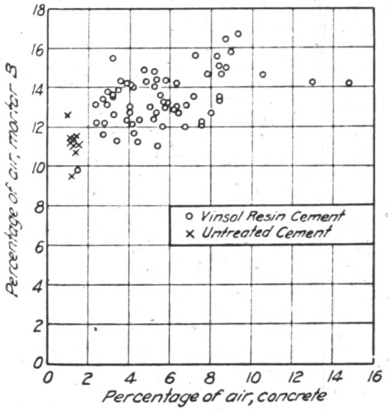

FIG. 8.—Relation of the Percentage of Air in the 1:3 Tension Test Mortar of 65 to 75 Per Cent Flow to the Percentage of Air in Concrete Made of the Respective Cements.

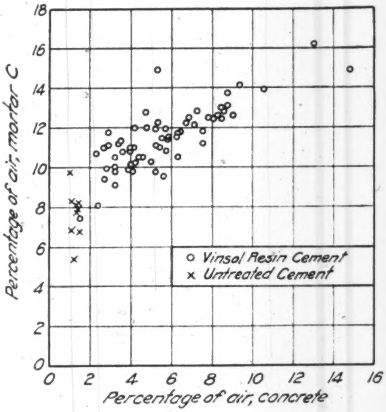

FIG. 9.—Relation of the Percentage of Air in the 1:2.75 Plastic Mortar of Constant Water-Cement Ratio to the Percentage of Air in Concrete Made of the Respective Cements.

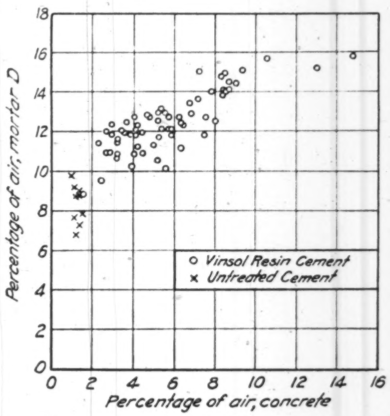

FIG. 10.—Relation of the Percentage of Air in the 1:2.75 Plastic Mortar of 100 to 115 Flow to the Percentage of Air in Concrete Made of the Respective Cements.

of the Vinsol resin mortars having air contents of 12 to 15 per cent.

It may be noted from Tables I and III that of the 49 cements requiring different amounts of water in the respective A and B mortars, 42 had less air in the drier of the two mortars and 7 had more air in the drier mix.

Mortars C and D.—The relations of the air contents of mortars C and D to the air contents of the concrete made of the respective cements are presented in Figs. 9 and 10. The trend of increase in air contents of mortars C and D with increase in air content of the concrete is more pronounced than was found with mortars A and B. The dispersion or scattering of the values of the various cements is believed too great for use of these mortars for performance tests. In mortar D, for example, values of 12 to 13 per cent of air in the mortar were obtained on cements whose concretes had air contents ranging from 2.5 to 8 per cent.

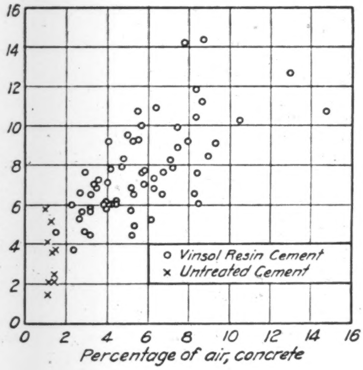

FIG. 11—Relation of the Percentage of Air in the Wet 1:3 Mortar to the Percentage of Air in Concrete Made of the Respective Cements.

It may be noted in Table III that the drier mortar D generally had more entrained air than the corresponding mortar C. This is opposite to what was found with the 1:3 mortars where the drier of the two mixes usually had the lesser entrained air. The majority of the plastic mortars C and D had less air than the 1:3 mortars of normal consistency (mortar A).

Mortar E.—The percentage of air as determined in the wet 1:3 mortar test plotted against the percentage of air in the concrete is presented in Fig. 11.

The spread of results obtained with the different cements may be exemplified by the following: Cements having 8 to 9 per cent air in the concrete had air contents of 6 to 14 per cent in mortar E, while on the other hand, cements having 7 to 8 per cent air in mortar E had air contents of 3 to 8 per cent in the concrete. It may also be noted in Table III that the wet 1:3 mortar had less entrained air than the relatively dry 1:3 mortars used for the tension test specimens.

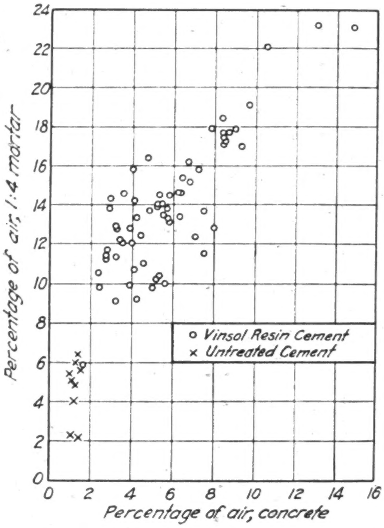

FIG. 12.—Relation of the Percentage of Air in the 1:4 Acceptance Test Mortar to the Percentage of Air in Concrete Made of the Respective Cements.

Mortar F.—The relation of the air content of the 1:4 mortars to the air content of concrete made of the respective cements is presented in Fig. 12.

From this figure it is evident that the ratio of the air content of the 1:4 mortars to that entrained in concrete is not the same for different cements. For example, cements whose concrete had 4 per cent air, had air contents in the respective 1:4 mortars ranging from 9 to 16 per cent. Similarly, 3 to 7.5 per cent of air was entrained in concretes made of the cements whose 1:4 mortars entrained 14 per cent of air.

Wuerpel and Weiner (5) indicated a ratio of about three to one between the air in the 1:4 mortar and that in the concrete. In the series of tests on the 64 Vinsol resin cements reported in this study, the ratio varied from 1.5 to 4.9. A different type of mixer was used for the concrete and the proportions used may not have been the same as used by Wuerpel and Weiner.

TABLE IV.—REPRODUCIBILITY OF VOLUME WEIGHT DETERMINATIONS.

	Percentage of Duplicate Batches Having Difference in Cup Weights as Indicated				
	1 g. or less	2 g. or less	3 g. or less	4 g. or less	5 g. or less
Mortar A	36	53	75	86	93
Mortar B	19	41	58	73	86
Mortar C	44	66	77	88	95
Mortar D	33	68	82	92	96
Mortar E	31	58	81	86	97
Mortar F	44	74	84	90	96
Paste L	75	92	95	97	97
Paste H	69	86	93	96	99

Only one determination of weight-per-cubic-foot of concrete was made for each of the cements, except that 7 determinations were made on one cement. The percentage air content of the concrete made of this cement ranged from 8.5 to 9.3, with an average of 8.9 per cent. The probable limit of uncertainty was ±0.24 (P_s = 0.9, 7 observations) (6). It, therefore, appears that the variance in the concrete weight-per-cubic-foot determinations was not sufficiently great to cause the scattering noted in Fig. 12. A number of determinations were made of the air content of the 1:4 mortars in which a 500-ml. cup was filled by the method required by Method C 185. The air content values checked reasonably well (see Table V) with those determined with the smaller cup, indicating that these differences in ratio of air content in concrete and mortar actually exist and are not entirely a function of size of measuring cup or method of placement of the 1:4 mortar.

The current limits of 10 to 18 per cent of air in the 1:4 mortar of the Tentative Specifications C 175 T-44 were not met by three Vinsol resin cements whose concrete had 3 to 5 per cent air, but they were met by twelve with air contents of concrete greater than 7 per cent and by seven with air contents greater than 8 per cent.

TABLE V.—SUPPLEMENTAL TESTS OF AIR CONTENTS AND FLOWS OF 1:4 MORTARS AS DETERMINED BY DIFFERENT METHODS.

Cement	Air Content, per cent				Flow		
	210-ml. Cup (vibrated)		206-ml. Cup	500-ml. Cup	Burmister Trough, in.		10-in. Flow Table, per cent[a]
	Orginal	Supplemental			Original Test	Supplemental Test	
No. 6	23.2	23.0	22.3	22.5	2.7	2.7	88
No. 7	23.1	23.2	22.7	23.1	2.7	2.7	91
No. 12	13.7	15.2	14.8	14.8	2.9	2.8	108
No. 17	9.9	11.4	11.0	10.2	2.5	2.4	102
No. 19	11.5	11.8	11.8	11.5	2.8	2.8	112
No. 33	10.2	10.6	10.5	9.9	2.8	2.6	102
No. 35	5.8	6.3	6.0	6.2	2.7	2.9	106
No. 49	9.8	9.1	8.4	8.6	2.8	2.6	102
No. 52	14.6	13.9	13.0	13.5	2.7	2.7	104
No. 53	14.5	14.7	14.0	14.3	2.8	2.8	97
No. 54	19.1	20.2	18.9	19.2	2.6	2.7	97
No. 58	22.1	21.3	20.2	20.1	2.8	2.5	90
No. 60	17.0	17.9	16.8	16.5	2.9	2.8	107
No. 62	10.5	11.5	9.8	9.7	2.4	2.4	90
No. 64	11.0	11.1	10.6	10.5	2.4	2.6	105

[a] Ten ½-in. drops.

Reproducibility of Entrained Air Values of Mortars and Pastes.—An analysis was made of the difference in volume weights of the first two of the batches prepared of each of the various mortars of each of the cements. The results are tabulated in

Table IV. With the size cup used in this investigation, a difference in volume weights of 1 g. corresponds approximately with a ±0.1 range in percentage air of the pairs of mortars. It may be noted that with the 1:4 mortar, about three quarters of the duplicate batches had a range of air contents of ±0.2 per cent or less. (The proposed specifications allow a ±1.0 per cent range in air contents of the duplicate mortars.) Of the types of mortars tested, the air contents of duplicate batches of the 1:3 mortar of 65 to 75 per cent flow were least reproducible and the duplicability of air contents of the pairs of the 1:4 mortars was as good as, or better than, was found with the other mortars tested.

In the supplemental series of tests on 15 of the cements reported in Table V, volume-weight determinations were made by three different methods on each of the 1:4 mortar batches. There was very little choice as to reproducibility of duplicate determinations in the three methods of determining the volume-weight relation. The 210-ml. cup method with vibration indicated slightly higher air contents than did the 500-ml. cup method. The air contents as determined by the vibrated 210-ml. cup method were in fair agreement with the values determined by the same method one to four months previously. A different sized batch was used in the later tests and the aging of the cement may also have been a factor. The Burmister trough flow values were in agreement with previously determined values.

The flow measurements made on these 15 cements indicated that flows of 2.4 to 2.9 with the Burmister apparatus corresponded roughly to flows of 100 ± 10 on the standard 10-in. flow table when using ten $\frac{1}{2}$-in drops. It appears, therefore, that the standard 10-in. flow table could be used in determining the water requirement of the 1:4 mortar.

DISCUSSION

A wide range of values of fineness, water requirements, flows, strength, and amount of Vinsol resin was obtained on the 64 Vinsol resin cements tested. The type of frequency distribution obtained for the various properties indicates the randomness of the sampling and adequacy of number of samples tested.

The tests here reported furnish information supporting some of the recent changes in the methods of test and specification requirements of Vinsol resin cements. These tests indicate that the use of the water requirements of the neat pastes of Vinsol resin cements to determine the amount of water for the 1:3 tensile strength mortar results in mortars which are usually too wet for satisfactory placement. If the tensile strength test, required by Federal Specification SS-C-191b and the recently rescinded Emergency Alternate Specifications (EA C 150) is used by the purchaser of the Vinsol resin cement, there is a definite need to change the specifications to require that the test specimens be made of mortars of about the same placeability as is attained by the untreated cements. Approximately three fourths of the Vinsol resin cements required less water by this method of proportioning the mortars for tensile strength tests than is required by the present specifications. For those cements where less water was required by the mortar of the 70 ± 5 flow range, there was a higher tensile strength for the drier of the two mixes.

The 1:2.75 plastic mortars of all of the Vinsol resin cements required less water when prepared according to the current Method C 109 – 44 where flow of 100 to 115 is specified than when prepared according to the previous A.S.T.M. Tentative Method C 109 – 43 T where a water cement ratio of 0.53 was specified. The resulting compressive strength values at the various ages were found to be appreciably greater in nearly every case.

The plastic mortar compressive strength test was proposed as a test method for cement by Committee C-1 in 1934 (7) because of the conclusions that this test is (1) less erratic, and (2) more indicative of the concrete strength than is the tensile strength test. The percentage dispersion in tensile strength values of the 64 different Vinsol resin cements is much less than the percentage dispersion in compressive strength values. The tension test was deleted from the requirements of Specifications C 175 in the recent revision of that specification.

In all of the graphs of the relation of the air contents of the various mortars to the air content of concrete, a considerable amount of scattering may be observed. It has been shown by Kennedy (3) that the air entrainment may be affected by the gradation of the fine aggregate. Because of this, a mortar test could hardly be expected to indicate air contents of all possible concrete mixes. In other words, the fact that a cement has a satisfactory air content in the 1:4 test mortar does not necessarily guarantee an acceptable air content in a concrete made of this cement. It appears that even with the use of an acceptance test mortar, careful field tests and field mix adjustments will be necessary if the air content of the concrete is to be controlled within narrow limits.

For the different cements, the 1:2.75 plastic mortars of 100 to 115 flow had from 1 to 10 times as much entrained air as the concrete and the difference in ratios of the amount of air entrained in the 1:3 tension test mortars to that in concrete was even greater. Moreover, the lack of constant relation between air contents of test mortars and concrete as shown in these tests may be one of the contributing reasons for differences in ratios of strength of mortar test specimens and strengths of concretes of any one proportion. It has been found from actual experience that the air contents of the various test mortars vary somewhat with different mixing procedures used by different operators. Difference in the air contents of test mortars is undoubtedly a factor contributing to the differences in strength results obtained from day to day by the same or by different operators. There appears, therefore, to be a definite need for a mechanical mixing device.

The 1:4 mortar had the greatest range in air content and was as satisfactory as any other mortar with respect to reproducibility and relation of air content to the air content of concrete. Since a wide range is a desirable feature of a performance test, the 1:4 mortar appears more appropriate for this purpose than other mortars or pastes tested in this investigation. This 1:4 mortar is the same as that required by the present Tentative Specifications for Air-Entraining Cement (C 175 – 44 T).[12]

The bulk-specific-gravity determined by use of the 210-ml. cup appeared satisfactory from the standpoint of reproducibility, but the calculated air content values were not identical with those obtained by use of the 500-ml. cup. There is a necessity, therefore, for using the specified size cup and method of filling the cup if results in various laboratories are to agree.

The tests indicated that a flow table, which is usually found in most cement testing laboratories, was suitable for measuring the consistency of the 1:4 mortar.

SUMMARY OF RESULTS

The chloroform-soluble material of the commercial Vinsol resin cements ranged from 0.007 to 0.123 per cent with the majority of the cements having from 0.025 to 0.045 per cent chloroform-soluble material. The amount of Vinsol resin determined by the methoxyl method on 13 of the cements was usually slightly lower than that determined by the chloroform-soluble method.

Turbidimeter tests indicated fineness values of the cements ranging from 1520 to 2420 sq. cm. per g. The ratio of air-permeability to turbidimeter fineness values ranged from 1.6 to 2.1.

The Vinsol resin cement neat pastes of "normal consistency" were generally more workable and stickier than the neat cement pastes of the untreated cements.

The 1 to 3 tension test mortars had flows ranging from 57 to 128 per cent for the different Vinsol resin cements when the percentage of water was based on that required by the neat cement pastes of normal consistency. The 1:2.75 plastic mortars had flows ranging from 120 to more than 150 per cent when using a constant water-cement ratio of 0.53.

The 7-day tensile strengths of the 1:3 mortars of normal consistency ranged from 250 to 530 psi., whereas the 1:3 mortars of 65 to 75 per cent flow had strengths ranging from 290 to 495 psi.

The 7-day compressive strength of the 1:2.75 plastic mortars of 0.53 water-cement ratio ranged from 1190 to 4620 psi., whereas the 7-day compressive strength of the 1:2.75 plastic mortars of 100 to 115 per cent flow ranged from 1400 to 5330 psi.

The compression test indicated a much greater difference in the relative strengths of the different cements than did the tension test.

The air contents of the neat pastes of water-cement ratio of 0.50 were not indicative of the air contents of concrete.

The air contents of the 1:3 tension test mortars of the Vinsol resin cements ranged from 9 to 17 per cent, whereas the 1:2.75 plastic mortars had a range of air contents of from 7.5 to 16.5 per cent. Using less water generally resulted in a lower air content in the 1:3 (20–30 sand) mortar and a higher air content in the 1:2.75 graded sand mortar. The 1:2.75 mortars were more indicative of the air content of the concrete than the 1:3 mortars.

The 1:4 mortars, as specified by Method C 185 – 44 T for test of air-entraining cements, had air contents of from 6 to 23 per cent for the Vinsol resin cements and from 2 to 6.5 per cent for the untreated cements.

Concrete proportioned 1:2.2:3.3 with a 3 ± 1 in. slump had air contents ranging from 1.5 to almost 15 per cent for the Vinsol resin cements and from 1 to 1.5 per cent for the untreated cements.

The ratio of the air content of the 1:4 mortar to the air content of the concrete ranged from 1.5 to 4.9.

Acknowledgment:

Acknowledgment is made to Bernard Bernstein, of the Bureau staff, for fineness determination and assistance with other tests. Acknowledgment is made to the following staff members for chemical determinations: B. Leonard Bean, Julian Berch, Cyril L. Crocker, Louis Fink, Milton Pollock, and Jeanette Williamson.

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(2) Report on Air-Permeability Method for Determining Fineness of Cement, ASTM BULLETIN, No. 118, October, 1942, p. 31.

(3) Henry L. Kennedy, "Entrained Air—Its Effect on the Constituents of Portland Cement Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 821 (1944).

(4) A.S.T.M. Manual on Presentation of Data.

(5) Charles E. Wuerpel and Albert Weiner, "The Reaction of Vinsol Resin as it Affects the Air Entrainment of Portland-Cement Concrete," ASTM BULLETIN, No. 130, October, 1944, p. 41.

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DISCUSSION

MR. CHARLES E. WUERPEL[1] (*by letter*).—The authors have made a welcome and valuable addition to the literature on cements containing air-entraining admixtures. Their extensive studies of the air content of mortars, using Tentative Method of Test for Air Content of Portland-Cement Mortar (A.S.T.M. Designation C 185)[2], and their studies of the ratio of the air content of mortar, so determined, to the air content of concrete, are particularly welcome to this writer since they parallel work done in this laboratory. The range in air contents of mortar (6 to 23 per cent) and the range in air contents of concrete (1.5 to 15 per cent) found by the authors confirm the conclusions reached at this laboratory regarding the erratic and often unpredictable behavior with respect to air entrainment of certain cements containing interground flake (unneutralized) Vinsol resin. It is regretted that the authors' studies included no cements containing *neutralized* Vinsol resin since: (*a*) The greater part of the data upon which Tentative Method C 185 was based[3] and all of the data regarding the ratio of air content of mortar to air content of concrete given in a paper[4] by the writer and Mr. Weiner were derived from tests of cements containing neutralized Vinsol resin; and (*b*) It has been found that the air content of concrete made with cement containing neutralized Vinsol resin is much less erratic than that of concrete containing flake (unneutralized) Vinsol resin. The authors compare the ratio of "about three to one" based on the values in the paper[4] by the writer and Mr. Weiner with those obtained in their tests which ranged from 1.5 to 4.9. It is noted that the concrete reported on by the authors was made with 1-in. gravel while that reported on in the paper[4] by the writer and Mr. Weiner was made with $\frac{3}{4}$-in. gravel and also with $\frac{3}{4}$-in. crushed stone. The test data presented graphically in the paper[4] are tabulated more completely in Table III of the report.[3] For gravel concrete, *five* cements with flake Vinsol resin showed an average ratio of air-in-mortar to air-in-concrete of 2.8 but a range of from 2.3 to 3.5 while *ten* cements with neutralized Vinsol resin showed an average ratio of 3.1 and a range of only 2.8 to 3.4. Similarly, for crushed-stone concrete, the five cements with flake Vinsol resin showed an average ratio of 2.4 with a range of from 1.7 to 2.8, while the ten cements with neutralized Vinsol resin, which also showed an average ratio of 2.4, had a range of but 2.2 to 2.9. By including the ratios for the plain cements, averages of 3.0 for gravel and 2.3 for crushed stone were derived.

Additional laboratory tests on concrete mixtures containing neutralized Vinsol resin added to the batch at the mixer and made with $1\frac{1}{2}$-in. crushed stone gave average ratios with three different cement factors as follows:

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[1] Engineer-in-Charge, Central Concrete Laboratory, Corps of Engineers, U. S. Army, Mount Vernon, N. Y.

[2] 1944 Book of A.S.T.M. Standards, Part II, p. 1227.

[3] Charles E. Wuerpel, "Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar," Appendix I to Report of Committee C-1, *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 306 (1944).

[4] Charles E. Wuerpel and Albert Weiner, "The Reaction of Vinsol Resin as it Affects the Air Entrainment of Portland-Cement Concrete," ASTM BULLETIN, No. 130, October 1944, p. 41.

Cement Factor, bags per cu. yd.	Ratio of Air Content of Mortar to Air Content of Concrete
4.5	2.46
5.25	2.95
6.0	2.95

Field experience on two large projects, referred to briefly in the closure to the paper[4] by the writer and Mr. Weiner, on which cement containing interground neutralized Vinsol resin was used with 2-in. crushed coarse aggregates gave values for air content of concrete, air content of mortar and ratios as follows:

Project	Air Content, per cent								Ratio Air Content of Mortar to Air Content of Concrete
	Mortar				Concrete				
	Number of Tests	Maximum	Minimum	Average	Number of Tests	Maximum	Minimum	Average	
1	5	16.0	13.2	15.2	6	3.4	2.5	2.9	5.2
1	6	16.4	13.0	15.4	6	4.5	3.9	4.0	3.9
1	6	17.0	13.2	15.9	8	4.9	4.5	4.7	3.4
1	5	18.5	14.5	17.6	5	5.3	4.9	5.1	3.5
2	7	18.6	18.1	18.3	7	4.8	3.4	4.3	4.25
2	12	21.5	16.3	18.4	12	4.9	3.4	4.2	4.3
								Average	4.2

It is thus evident that cements containing neutralized Vinsol resin are not subject to the same degree of unpredictability of air entrainment as cements containing flake Vinsol resin. It is nevertheless true that the factors of size and shape of aggregates, type and duration of mixing, cement and water content of the mixture, as well as type and amount of the air-entraining admixture limit the extent to which the air content of the concrete may be predicted from determinations of the air content of the Tentative Method C 185 mortar. With a greater knowledge of the effect of these influences and with a greater number of air-entraining admixtures being proposed for use in concrete, the conclusion appears to be indicated that the close regulation of the amount of air to be entrained in a concrete mixture can be accomplished most practically by addition and adjustment, at the mixer, of the quantity of admixture used.

The authors' conclusion that the 10-in. flow table is suitable for measuring the water demand of the mortar required in Tentative Method C 185 is not supported by studies made in this laboratory. The authors state that "flows of 2.4 to 2.9 with the Burmister apparatus corresponded roughly to flows of 100 ± 10 on the standard 10-in. flow table . . . therefore the standard 10-in. flow table could be used. . . ." A "rough" correspondence does exist, but a significant correlation between the data obtained using the two types of apparatus is not shown by the values given in the authors' Table V. Cement No. 6 had a flow of 2.7 in. in the trough and 88 per cent on the table, whereas cement No. 64 had a trough flow of 2.5 in. and a table flow of 105 per cent. The average trough-flow and comparable table-flow data from Table V are plotted in the accompanying Fig. 1, and the correlation coefficient is found to be 0.48. In the absence of a significant correlation between the results obtained using the two types of apparatus, this writer does not feel that the 10-in. flow table may be used interchangeably with the flow trough to

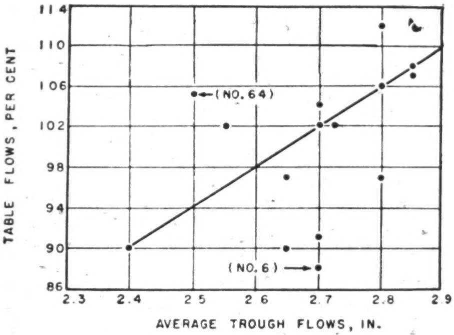

FIG. 1.—Relation of Trough-Flow and Table-Flow Data and Correlation of These Values Proposed by Blaine, Yates and Dwyer.

Values from Table V; solid line indicates authors' proposed correlation. Cements Nos. 6 and 64 are mentioned in text.

control the water content of the C 185 mortar.

MR. DUFF A. ABRAMS[5] (*by letter*).—In 1917 the writer first called attention to the fundamental importance of the water-cement ratio of mortar and concrete mixes. At that time only strength and wear resistance had been studied. The intervening 28 years showed that most of the basic features of concrete are closely bound up with this function. Nearly every passing year adds another item to the long list of concrete properties that are identified with this ratio. In 1944 the writer found[6] that the coefficient of variation of repeat compression tests of concrete was an inverse function of the strength, which for a given cement and age is dependent on the water-cement ratio.

The authors of the paper under discussion gave no attention to the water-cement ratios of the various mixes used in studying the air-entraining properties of Vinsol-resin portland cements. By their failure to suspect this relationship before the tests were made, much unfruitful work was done; by failure to observe its significance after the tests were completed, they missed the only important features of their data and were thereby led to a number of inconsequential conclusions, some of which are erroneous. Interpreting the data in terms of water-cement ratio leads to a number of clarifying and practical results and shows that many of the presently-held beliefs and practices with reference to the behavior of air-entraining cements are untenable.

Effect of Water-Cement Ratio on Mortar Strength:

The following are the only statements in the paper on the water-cement ratio:

> "With some cements a slight decrease in water caused a greater increase in strength than did a larger decrease in water with other cements." (page 744)
>
> "As was the case with tension tests, the relation between the increase in compressive strength and the decrease in mixing water was not the same for all cements." (page 746)

This seems to be a serious indictment of the validity of the water-cement ratio law announced by the writer 28 years ago,[7] and led to an examination of the data on which the conclusions were based. The accompanying Table I is a summary of data in the paper, using average values for 64 Vinsol-resin cements in Tables I and II. An average increase of 5½ per cent in water-cement ratio resulted in an average decrease of 7½ per cent in 28-day strength. Slightly higher decreases were found at 3 and 7 days. This is about the same decrease that has been shown by hundreds of series of tests made in all parts of the world during the past 30 years. Minor departures from the general relationship were probably due to the fact that the tests in the paper were

TABLE I.—EFFECT OF WATER-CEMENT RATIO ON MORTAR STRENGTH.

Averages of 64 Vinsol-resin cements in Tables I and II.

Mortar	Water-Cement Ratio	Mortar Strength, psi.		
		3 days	7 days	28 days
TENSION TESTS				
A	0.432	280	355	435
B	0.412	315	390	465
Ratio A/B	1.05	0.89	0.91	0.93
COMPRESSION TESTS				
C	0.53	1350	2190	3650
D	0.50	1550	2440	3990
Ratio C/D	1.06	0.88	0.90	0.92

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[5] Consulting Engineer, New York, N. Y.

[6] Duff A. Abrams' discussion of paper by S. P. Wing, Walter H. Price, and Clemeunt T. Douglass, "Precision Indices for Compression Tests of Companion Concrete Cylinders," *Proceedings*, Am. Soc. Testing Mats., Vol. 44, p. 852 (1944).

[7] Duff A. Abrams, "Design of Concrete Mixtures," *Bulletin 1*, Structural Materials Research Laboratory, Lewis Institute, Chicago, Ill., (1919).

insufficient in both number and scope to establish reliable factors for the water-cement ratio – strength relation for mortars made of the individual cements. With only two batches of mortar and a range of water-cement ratio of $5\frac{1}{2}$ per cent, it should not have been surprising that the tests would, in some instances be inconsistent.

Conclusion 1.—A few cements showed irregularities in the water-cement ratio – strength relation, but the average of 64 Vinsol-resin cements furnished an excellent verification of the water-cement ratio law for mortars made of a new type of portland cement.

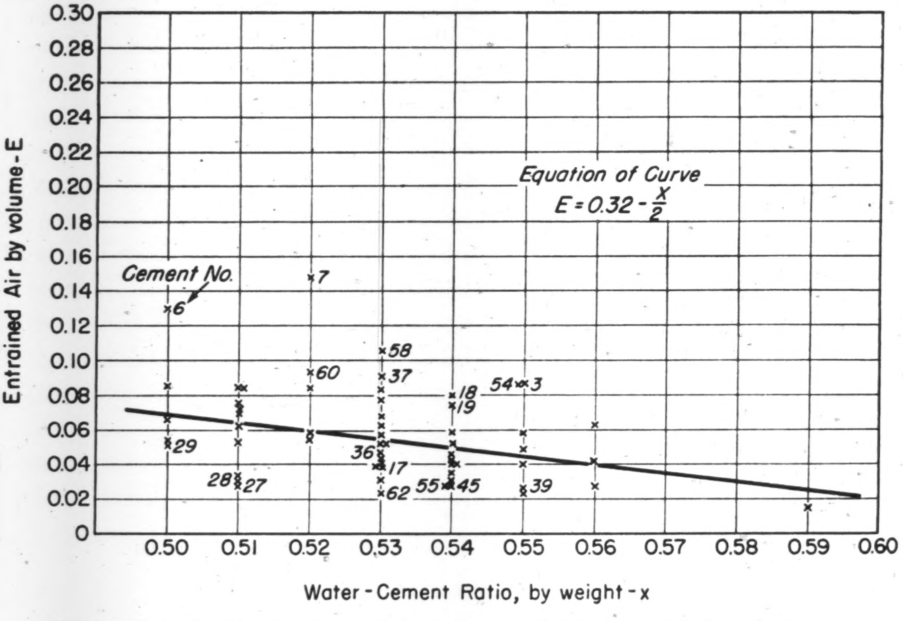

FIG. 2.—Relation Between Water-Cement Ratio and Entrained Air in 1:$5\frac{1}{2}$ Concrete.

Water-Cement Ratio the Key to Quantity of Air Entrained by Vinsol-Resin Cements:

The tests of mortars A, B, C, D, E, and on pastes H and L, can be dismissed as having little significance as measures of the air-entraining value of a cement in concrete. Mortars A, B, D, gave 11 to 8 per cent of air for the untreated cements, and only 2 to 4 per cent more when Vinsol resin was present, hence these mixes are clearly not adapted to the tests of cements that are known to be air-entraining in concrete. Mortars C and E were tested in such a manner that it is impossible to interpret the data. Cement-water pastes H and L gave low and erratic values and frequently conflicting results. This leaves mortar F concerning which the authors stated (p. 751):

> "The 1:4 mortar had the greatest range in air content and was as satisfactory as any other mortar with respect to reproducibility and relation of air content to the air content of concrete. Since a wide range is a desirable feature in a performance test, the 1:4 mortar appears more appropriate for this purpose than other mortars or pastes tested in this investigation."

The writer would go farther and say that mortar F was *the only one of the mortars or pastes tested that was significant* as a measure of the air-entraining properties of Vinsol-resin cements. The reasons for this conclusion will become apparent.

The only studies reported by the authors (Figs. 7 to 12) showing the interrelation of air in mortars and concrete overlooked entirely the most significant features of the data.

The accompanying Fig. 2 shows entrained air of the 1:5½ concrete plotted as a function of the water-cement ratio of the same mix. It is difficult to discover any pronounced relationship; if this diagram were plotted with a condensed scale of water-cement ratios, it would resemble a gunshot scatter. The exaggerated scale of water-cement ratio used indicates a slight but unconvincing tendency for entrained air to decrease as water-cement ratio increases, as shown by the line. The scattering of points in this figure duplicates the results shown in Figs. 7 to 12 of the paper, where the authors did not even attempt to draw curves.

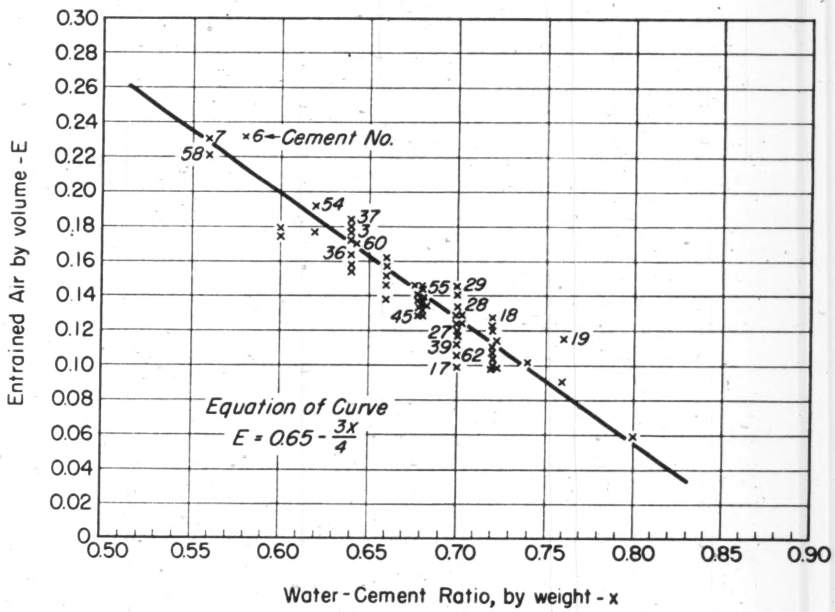

FIG. 3.—Relation Between Water-Cement Ratio and Entrained Air in 1:4 Mortar F.

The accompanying Fig. 3 shows an arrangement of the data for 1:4 mortar F in a manner similar to Fig. 2. Here a very definite relation was found which shows that in this mortar mix entrained air is an inverse function of the water-cement ratio. In Fig. 3 only three tests (4½ per cent) departed more than ± 15 per cent from the curve; in Fig. 2, 44 tests (65 per cent) fell outside the ± 15 per cent limits. The uniformity of the relation in Fig. 3 is a sharp contrast with the scattering in Fig. 2 and in Figs. 7 to 12 of the paper.

The straight lines in Figs. 2 and 3, can be expressed by equations of the form $E = C - D x$, where E is entrained air, by volume, x is water-cement ratio, by weight, and C and D are constants.

The relations are given by:

$$\text{Concrete (Fig. 2)}..E = 0.32 - \frac{x}{2}..(1)$$

$$\text{Mortar F (Fig. 3)}..E = 0.65 - \frac{3x}{4}..(2)$$

Conclusion 2.—For 1:4 mortar F the water-cement ratio required to produce standard workability is the key to the quantity of air entrained by Vinsol-resin cement.

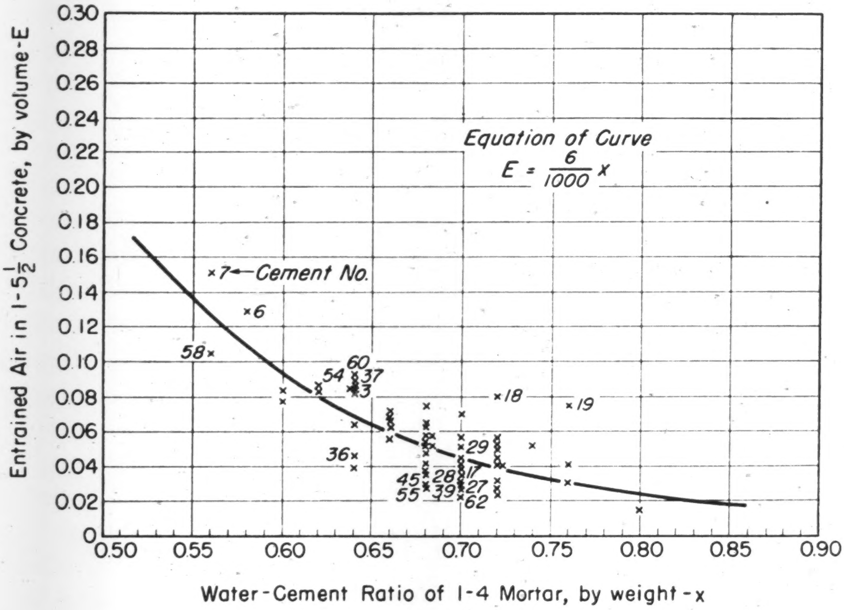

FIG. 4.—Relation Between Water-Cement Ratio of Mortar F and Entrained Air in 1:5½ Concrete

Conclusion 3.—With the data of the paper it is not necessary to determine the air content of 1:4 mortar. For routine tests of a cement that is known to contain Vinsol resin, all that is needed is the water-cement ratio required to produce standard workability; the air content can be read from Fig. 3, or computed from Eq. 2.

The accompanying Fig. 4 shows the most instructive and practical applications of the data where water-cement ratio of mortar F was plotted as abscissa and air content of concrete as ordinate. The curvilinear relation shown by this figure presents a new and significant feature of the behavior of Vinsol-resin cements. Much of the variability of the concrete in Fig. 2 is reflected in this diagram; however, the trend of the values is unmistakable. In view of the regularity of Fig. 3, it is obvious that the bulk of the deviations in Fig. 4 must be charged to concrete rather than to the mortar. The reasons for the wide departures can be found in the variations in workability discussed below.

The curve in Fig. 4 may be represented by an exponential equation of the form:

$$E = G/H^x \ldots\ldots\ldots(3)$$

where: E is entrained air in concrete, x (an exponent) is water-cement ratio of mortar F, and G and H are constants.

After determining the constants, Eq. 3 becomes:

$$E = \frac{6}{1000^{x}} \quad \ldots\ldots\ldots(4)$$

It may be thought, at first sight, that this equation with a fractional exponent, is difficult to solve; but on the contrary, it is quite simple. Assume $x = 0.60$:

$$\log E = \log 6 - x \log 1000,$$

$$= 0.778 - 3x = 8.978,$$

$$E = 0.095 \text{ or } 9.5 \text{ per cent}$$

The solution of Eq. 4 may be stated in a short rule:

From 0.78 subtract $3x$; the remainder is log E. A little mental arithmetic and one slide-rule reading solve the equation for any water-cement ratio of mortar F.

Conclusion 4.—The algebraic relation between water-cement ratio of mortar F and the air content of 1:5½ concrete is similar to that found by the writer for the water-cement ratio - strength relation, which was expressed by the equation

$$S = A/B^{x}$$

where: S is compressive strength of concrete at a given age, x (an exponent) is water-cement ratio, and A and B are constants.[7]

Two other important conclusions are drawn from Fig. 4.

Conclusion 5.—The quantity of air entrained in 1:5½ concrete by a Vinsol-resin cement was more accurately predicted by the water-cement ratio of mortar F than by the water-cement ratio of the concrete itself.

Conclusion 6.—Knowing the water-cement ratio required by a Vinsol-resin cement to produce standard workability in mortar F, the amount of air in the 1:5½ concrete can be read from Fig. 4, or computed from Eq. 4.

It is probable that the straight line in Fig. 3 should have been an exponential curve, similar to Fig. 4, but the data do not justify plotting a curve. The straight line is somewhat more simple to use. Besides, this curve assumes a minor significance since we saw that its principal field of usefulness has been usurped by Fig. 4.

Conclusion 7.—This discussion emphasizes the need for unusual care in the determination of water-cement ratio of standard 1:4 mortar. It also suggests that this test should be substituted as a specification requirement, for the present test of quantity of entrained air.

TABLE II.—STUDY OF 18 IRREGULAR TESTS IN ACCOMPANYING FIGS. 2, 3, AND 4.

Cement	Rating of Tests in		
	Fig. 2	Fig. 3	Fig. 4
No. 3	Very high	Regular	Regular
No. 6	Very high	High	Regular
No. 7	Very high	High	Regular
No. 17	Low	Very low	Regular
No. 18	High	High	Very high
No. 19	High	High	Very high
No. 27	Very low	Regular	Low
No 28	Very low	Regular	Regular
No. 29	Low	High	Regular
No. 36	Regular	Regular	Low
No. 37	High	Regular	High
No. 39	Low	Regular	Low
No. 45	Low	Regular	Low
No. 54	Very high	Regular	Regular
No. 55	Low	Regular	Very low
No. 58	Very high	Regular	Regular
No. 60	High	Regular	High
No. 62	Very low	Low	Very low

Study of 18 Irregular Tests:

A special study was made of 18 tests that showed the greatest departures from the normal relationships between water-cement ratio and entrained air, in Figs. 2, 3, and 4. One phase of this study is shown in the accompanying Table II. It should be noted in the beginning that all of the 18 tests did not show irregularities in all diagrams.

There was little consistency in the tests that showed greatest irregularities. The largest number of irregularities occurred in Fig. 2, where water-cement ratio of 1:5½ concrete was plotted as abscissa and quantity of entrained air as ordinate. Fewest irregularities occurred in Fig. 3, where the water-cement ratio of 1:4 mortar F was plotted as abscissa and entrained air as ordinate. All but 7 tests in Fig. 3 were rated "regular" in Table II; that is, they conformed fairly to the trend of the curve. In Fig. 4, where water-cement ratio of 1:4 mortar F was plotted as abscissa and entrained air in 1:5½ concrete as ordinate, all but ten of the tests were rated "regular."

It does not seem reasonable that the same cement should entrain a small quantity of air in concrete and a large amount in mortar, or *vice versa*. There were two cements (Nos. 18 and 19) that gave consistently high values of entrained air for a given water-cement ratio; two cements (Nos. 27 and 62) gave consistently low values.

It is evident that most of the irregularities in Fig. 4 are chargeable to variations of air content of the concrete rather than to the water-cement ratio of the mortar. For example, in Fig. 2, cements Nos. 3 and 7 showed widest discrepancies (too high); but in Fig. 4 both conformed fairly to the curve. Cement No. 58 is notable in that it moved from one of the highest in Fig. 2 to a position below the curve in Fig. 4.

Conclusion 8.—The bulk of the wide deviations of plotted points from the curves in Figs. 2, 3, and 4 can be charged to variations in tests.

Further discussion of variations of tests is given below.

Effect of Entrained Air on Mortar Strength:

The only tests in the paper that are usable as a measure of the effect of entrained air are the compressive strengths of mortars C and D. The writer plotted the relation between the air content of mortar F and the average strengths of mortars C and D. It was thought that more would be gained by averaging them than by attempting to study the mortars separately, since differences in water-cement ratio and flow would be somewhat counter-balanced by the greater number of tests. At 28 days this relation is:

$$S \doteq 4800 - 7500\,E \ldots\ldots (5)$$

where: S is compressive strength, and E is volume of entrained air in mortar F.

This suggests a strength with no entrained air of 4800 psi. With $E = 0.15$ (about the average), $S = 4800 - 7500 \times 0.15 = 3700$ psi., representing a loss of 1100 psi., or 23 per cent.

Conclusion 9.—Each 1 per cent of entrained air, as determined by the 1:4 standard mortar test produced a loss in compressive strength of mortar of 2½ per cent at 3 days, 2 per cent at 7 days, and 1½ per cent at 28 days.

Since 19 of the cements, or 30 per cent of the total, showed air contents between 15 and 23 per cent, the above figures indicate serious strength losses for many of the cements.

Conclusion 10.—On the basis of the present specification limits of 10 to 18 per cent of entrained air in 1:4 mortar, a loss in 28-day strength of 1:2.75 mortar of 15 to 27 per cent would be expected.

The paper gave no tests of strength of concrete made of Vinsol-resin cements.

Variations of Mortar Strength:

Table II of the paper gave the following average coefficients of variation of strengths of 64 Vinsol-resin cements:

Specimen	3 days	7 days	28 days
Cube (compression)	20½%	22%	18%
Briquet (tension)	13	10½	8

In discussing these coefficients, the authors stated:

> "A small coefficient of variation indicates that there was little difference in the strengths of the different cements; conversely, a large coefficient of variation indicates large differences in strengths of different cements."

This states a general principle of statistics, but the authors were unfortunate in applying it to what is probably the only exception to the rule in the whole realm of materials testing. It is obvious that the coefficients for both cubes and briquets cannot correctly represent the variations of these cements. There are three cases: (1) coefficients decrease with age at test; (2) coefficients are affected by number of tests; (3) coefficients were much lower for the briquets than for the cubes. The writer has considered cases (1) and (2) in a discussion of another paper[6] where it was shown that:

> "The coefficient of variation of concrete cylinders tested at 28 days increases as a logarithmic function of the number of tests, and for a given number of tests, varies inversely as the strength of the concrete."

The above relationship was confirmed by the tests now under discussion, in that coefficients of both cubes and briquets tended to decrease with age, another way of saying with strength.

Case 3.—Instead of representing the superior merits of the briquet as an acceptance test for cement, it can be shown that the low coefficients of the briquets are fictitious, and have a meaning entirely different from that suggested by the paper.

Mortars generally fail at a unit elongation of about 0.001. The most-stressed section of a briquet is only a small fraction of an inch long, hence it is obvious that there is no opportunity for the stress to become distributed uniformly across the section. The briquet represents a clear case of eccentric loading, which results in failure by a tearing action, rather than by true tension, hence the computed stress at failure is much lower than the actual tensile strength. The older and stiffer the mortar, the more pronounced this discrepancy becomes. This forces a levelling of all briquet strengths, and accounts for another phenomenon that is frequently observed, namely, briquet strength increases up to 1 to 3 months, and thereafter declines until at 1 year the strength is about the same as at 7 days, while the compressive strength of mortar or concrete made of the same cement continues to increase indefinitely.

During the past 50 years much experimental evidence has accumulated which shows the extent of this tearing action in the briquet. In 1895 C. L. Durand-Claye[8] gave an analytical method for computing the stress across the minimum section of a briquet. In 1896 A. Foppl[9] showed the wide variations in the stresses in a briquet by measurements on an india-rubber model. In 1897 J. B. Johnson[10] applied Durand-Claye's analysis to a briquet. In 1912 E. G. Coker[11] showed the wide range in these stresses by means of photoelastic observations on glass or celluloid models. A similar method was used in 1939 by Anderegg, Waller, and Fried.[12] All of the foregoing studies showed high concentrations of stress at the edges of the waist of the briquet; three of them gave definite factors for the ratio of maximum to average stress, as follows:

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[8] C. L. Durand-Claye, "Annales des Ponts et Chaussees," June 1895.

[9] August Foppl, "Vorlesungen uber Technische Mechanik," 9th Ed., Vol. III, p. 68; see also "Zwang und Drang."

[10] J. B. Johnson, "Materials of Construction," 1st Ed., Wiley, New York, N. Y., 1897.

[11] E. G. Coker, "Distribution of Stress at the Minimum Section of a Cement Briquet," *Proceedings*, VI Congress Int. Assn. Testing Mats., Paper XXVIII₄, 1912.

[12] F. O. Anderegg, R. Weller, and B. Fried, "Tension Specimen Shape and Apparent Strength," *Proceedings*, Am. Soc. Testing Mats., 1939, p. 1261.

Authority	Date	Ratio of Maximum to Average Stress
Johnson	1897	1.54
Coker	1912	1.70
Anderegg	1939	1.78

The paper furnishes excellent material for a study of the levelling effect of the briquet test. For example, the 28-day compressive strength of cement No. 35, mortar D, was 6610 psi.; the next three high values were 5410, 5330, 5130, average 5290 psi. The 28-day tensile strength of cement No. 35, in mortar B was 550 psi.; the next three values were 555, 545, 540, average 547 psi. The increase of cement No. 35 over the average of the next three values was: cube 25 per cent, briquet 1 per cent. In the cube tests the next strength was 18 per cent below that of cement No. 35; for the briquets one half of the cements fall within this 18 per cent range. Similar factors were obtained with mortars C and A.

Using the average of all cements in Table II, the briquet strengths were the following percentages of cube strengths:

Age, days	Average Strength, psi.		Ratio B/C, per cent
	Cubes	Briquets	
3	1450	298	21
7	2310	372	16
28	3820	450	12

Instead of 450 psi. as the average 28-day strength of briquets, the true tensile strength was about 450 × 1.7 = 765 psi.

The trend of the above value suggests that at 3 days the levelling effect of the briquet is minimized and the B/C ratio is 21 per cent. It is interesting to note that if we take the ratios of the above percentages at 3 and 28 days, we secure $21/12 = 1.7$, which is the same factor that was determined by direct observations by Coker in 1912 and by Anderegg in 1939.

Another measure of the levelling of briquet strengths is found in the rate of gain in strength. Using the average of all mortars in Table II, the increase was:

Period	Increase in Strength, per cent	
	Cube	Briquet
3 to 7 days	58	25
7 to 28 days	65	21
3 to 28 days	161	51

Variation in repeat tests of a manufactured material is a function of technique, which includes sampling and all other steps. There is no reason why the tensile strength of mortars should be more variable than the compressive strength, if equal care is used in mixing, sampling, molding, and testing both specimens. That briquets gave a much lower variation than cubes shows only that there was an important difference in technique. This difference can be easily located in the unscientific method of loading the briquet.

Conclusion 11.—Instead of being a merit, the low coefficients of variation of the briquets are true measures of the deficiency of this test.

If one wishes to show that "all cements are alike," the briquet is the best test; if one wishes to learn the actual relative strengths of cements, compression tests must be used.

The briquet is a carry-over from the infancy of the art. The earliest use of the briquet-form of specimen in tests of portland cement that has come to the writer's attention, was by G. F. White, who adapted it about 1850 from the practice of stone testing. Tests of this type were among those made on portland cement at the Great Exposition, London, 1851. (*Proceedings, Inst. Civil Engr.*, Vol. 11, p. 478 (1852).) This test specimen was further popularized by John Grant[13] on the London Main Drainage

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[13] John Grant, "Experiments on Strength of Cement," *Proceedings*, Inst. Civil Engr. London, 1865-66 and 1870-71; also book of same title, 1875.

Works, about 1859, the first large project on which portland cement was used. The briquet has undergone no essential improvement since it first came into use 95 years ago.

During the past 40 years, the inadequacy of the briquet has been commented on by a number of American writers, in addition to those already cited[14, 15, 16]. Erroneous attempts to reconcile the composition and other properties of cements, the quality of aggregates, and the behavior of mortars and concretes, with the vagaries of the briquet strengths has been responsible for much of the confusion that has characterized cement and concrete technology in the United States during the past 60 years.

Conclusion 12.—The above analysis shows why the authors found much lower coefficients of variation for briquets than for cubes, and why briquet coefficients are fictitious and erroneous; also why briquet strengths are generally contradictory and misleading.

Conclusion 13.—Much of the confusion of the paper resulted from fruitless attempts to reconcile the tensile and compressive strengths of mortars.

Now that we have entered the atomic age, the briquet should be permanently banned as an instrument of either research or acceptance tests of cement. Ninety-five years is long enough for an art to be bedevilled by an unscientific test specimen.

Variations of Workability:

The authors discussed at some length the "Reproducibility of Entrained-Air Values of Mortars and Pastes," also variations in tests of unit weight of mortar and concrete. It appears that the reproducibility tests were all made on the same day, hence they are not representative of the typical case where tests must be made on different days. We saw above that for both mortar F and the concrete, the air content was a function of the water-cement ratio of the mix. This emphasizes the fact that unit weight is only one of the factors involved. The water-cement ratios actually used in the tests were determined by one of three measures of workability: (*a*) flow table, (*b*) flow trough, and (*c*) slump. The tests of mortar F were by far the most consistent of those reported. This is an argument for the use of the flow trough in this test.

The workability of concrete was determined by slump. Slumps within the range 3 ± 1 in. were accepted. Expressed in this way it may not appear to be a very wide range. Since no actual slumps were given and the number of tests is unknown, it is impossible to derive exact limits. Let us assume that the slumps that fell within the range 2 to 4 in. were the average of two tests. In order to secure the range of the larger "universe" the range as determined by two tests must be multiplied by 1.8; the accepted range of slump would then be $1.8 \times 2 = 3.6$ in. For this type of concrete the quantity of mixing water must be increased about 5 per cent in order to produce an increase in slump of 1 in. A 3.6-in. range in slump would then mean a range in water-cement ratio of $5 \times 3.6 = 18$ per cent. This range of 18 per cent in water-cement ratio would account for a range of about 33 per cent in strength of concrete due to this cause alone.

Tests in Table V show that for a flow-trough range of 2.7 to 2.8 in. the flow-table range was 88 to 112, or 27 per cent. As additional evidence that a flow-table range of 27 per cent for mortars that were supposed to be of similar work-

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[14] W. P. Taylor, "Notes on Cement Testing," 2nd Annual Convention, Assn. Am. Portland Cement Mfgr., Dec., 1904.

[15] "Data Considered by Committee C-1 in Preparing the Standard Specifications and Tests for Portland Cement," Section II, Part VII, Report of Subcommittee VII on Strength, p. 59, Am. Soc. Testing Mats., 1919. (Issued as separate publication.)

[16] S. Timoshenko, "Strength of Materials," Part II, 2nd Ed., 1941.

ability was not unusual, attention is called to Table I which shows:

Mortar B, flow-table range	22 per cent
Mortar D, flow-table range	16 per cent

It is interesting to note that the 22 per cent range came in adjacent cements (Nos. 27 and 28), in other respects almost identical.

Regardless of the accuracy of the air-content tests repeatedly stressed in the paper, we cannot escape the conclusion that the mortar tests, with the single exception of mortar F, had a range of values of the order of 22 per cent, and the concrete of the order of 100 per cent. The point is that while the method of test used by the authors determined the air content correctly for a given consistency (water-cement ratio), the consistency used varied widely.

Conclusion 14.—The wide scatterings of points shown in Figs. 7 to 12 were due not only to errors in tests of air content, but also to the wide variations in the water-cement ratios of the mixes on which air contents were determined.

When two factors are involved, nothing is accomplished by accurate control of one if the other varies widely; the less accurate factor governs the final results.

Additional Data Needed:

Vinsol-resin cements have been before the profession for five or six years. Dozens of reports of tests have been published, but most of them are of questionable value due to limited scope, absence of scientific controls, or the neglect of other essential factors. The present paper fails to give an answer to the fundamental question of the basis of the quantity of air entrained by a Vinsol-resin cement, in terms of the actors that go to make up a mortar or concrete mix, such as composition and quantity of cement, size and grading of aggregate, water-cement ratio, etc.

The following table gives the principal features of mortar F and the concrete of the paper, together with the average amounts of entrained air. The last line is an assumed pavement concrete.

Mix	Aggregates		W/C	Entrained Air, per cent
	Maximum	Fineness Modulus		
Mortar F (1:4)	No. 20	2.77	0.67	15
Concrete (1:5½)	1 in.	4.87	0.53	5½
Pavement concrete (1:5½)	2½ in.	6.20	0.45	??

The data in the paper suggest that the quantity of entrained air is a direct function of the quantity of cement. If so, the assumed pavement concrete would be expected to have zero air content.

The data show that the quantity of entrained air is an inverse function of the maximum size of aggregate. If so, the assumed pavement concrete would be expected to have zero air content.

The data show that the quantity of entrained air is an inverse function of the fineness modulus of the aggregate. If so, the assumed pavement concrete would be expected to have zero air content.

The data of the paper suggest that the quantity of entrained air is an inverse function of the size of batch. If so, the assumed pavement concrete would have zero air content.

Conclusion 15.—All evidence of the paper suggests that for concrete of the type generally used in pavements, the quantity of air entrained by the average commercial Vinsol-resin cement is zero.

It is the writer's belief that the small batches of concrete usually mixed in the laboratory have little or no significance as compared with field practice where mixers of 2, 3, 4, 6, and 8 cu. yd. are used.

The thoughtful engineer will demand definite answers to the above questions before he is willing to accept Vinsol-resin cement as an air-entraining agent. The larger question of the beneficial effects of air-entrainment on the durability of concrete must be approached in the same manner.

It may be objected that the laws governing entrainment of air in concrete are not a part of cement testing; on the other hand, the correct formulation of these laws is essential before a rational interpretation can be made of the cement tests. A more complete knowledge of the properties of air-entrained concrete may suggest many desirable modifications in test procedure as well as in the specification requirements for Vinsol-resin cements.

EFFECT OF HEAT ON PORTLAND CEMENTS CONTAINING VINSOL RESIN*

By Leonard Bean[1] and Albert Litvin[1]

It has been reported by some manufacturers of Vinsol resin cements that large losses of resin have occurred sometime during the manufacturing processes. One mill experienced losses as high as 75 per cent of the resin added to the clinker. At this plant it was claimed that during the finish grinding process the odor of Vinsol resin was quite pronounced. Officials of the company reported that in the freshly ground cement temperatures as high as 300 F. or even 350 F. were frequently found.

The problem was presented to the National Bureau of Standards in an endeavor to ascertain the cause of these losses of Vinsol resin during grinding and what effect they might have on the air-entraining properties of the finished cement. A study of this problem was accordingly undertaken.

Scope of Tests

The effects of duration and intensity of heating of powdered Vinsol resin on its weight, its chloroform-soluble content, its methoxyl content, and its air-entraining properties were determined by heating Vinsol resin alone and as interground in cement. Two methods of heating were employed, oven heating and heating in a laboratory rotary calciner. The effect of fineness of Vinsol resin intermixed with cement on the air-entraining properties of the cement was also studied.

Experimental Procedure and Results

Oven Heating:

One kilogram of cement was mixed with 0.045 per cent of its weight of Vinsol resin in a small pebble mill. The cement was removed and analyzed for Vinsol resin by the methoxyl method.[2] Only 0.031 per cent was found, indicating a large loss on the pebbles and the container.

This treated cement was then heated at 300 F. for varying periods. The heating was accomplished by placing the beaker containing the treated cement in an electrically heated oven. At intervals, the beaker and contents were removed, cooled, a 40-g. sample removed, and Vinsol resin content determined.[2] Results are given in Table I.

A 1-g. sample of straight Vinsol resin in a beaker was heated under the same conditions and its loss in weight and appearance noted. At the end of 2 hr. this Vinsol resin had carbonized to a considerable extent, indicating at least some decomposition at that temperature (300 F.).

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* Also published in ASTM Bulletin, No. 135, August, 1945, p. 30.

[1] National Bureau of Standards, Washington, D. C.

[2] 1944 Book of A.S.T.M. Standards, Part II, p. 1223.

Table I also shows the Vinsol resin lost in the separate sample of straight resin.

TABLE I.—EFFECT OF HEATING AT 300 F. ON VINSOL RESIN, AND ON CEMENT-VINSOL RESIN MIXTURE.

The second column shows Vinsol resin found by the methoxyl method; the third column is a calculation of resin lost, based on the original amount present shown in the second column; the fourth column shows losses based entirely on change in weight.

Total Time Heated, hr.	Cement-Vinsol Resin Mixture		Straight Vinsol Resin
	Resin Found, per cent by weight of cement	Resin Lost, per cent of 0.031	Resin Lost, per cent
0...	0.031	0	0
2...	0.025	19	19
4...	...	..	20
6...	...	..	22
8...	0.020	36	23
10...	...	..	23
14...	0.018	42	23
31...	0.009	71	24
51...	0.009	71	25

The work summarized in Table I indicates that Vinsol resin is lost from cement by heating at a temperature of 300 F. Since the decomposition noted in the resin at that temperature should certainly be suspected of changing the characteristics of the resulting product, a number of experiments were made in which Vinsol resin was heated in an oven at temperatures of 100, 200, and 300 F. for varying lengths of time up to 8 hr. This material was then ground with a mortar and pestle and added to cement by mixing in a pebble mill. The chloroform-soluble material in the cements was determined. Mortars were made from the cements and their densities determined.[3] The results were rather inconclusive. The differences caused by heating for these periods were not much greater than differences obtained on duplicate determinations using the same cement.

Vinsol resin is a material which, apparently, depends on neutralization for its air-entraining properties. The part of this reaction which produces air entrainment takes place during the brief mixing period of the mortar. Therefore, the particle size of the powdered resin used, when mixed with cement, might be expected to influence the air entrainment. At the suggestion of John Tucker, Jr., an effort was made to ascertain the magnitude of the effect of fineness. Accordingly, Vinsol resin which had a fineness, as received, of 2500 sq. cm. per g., as determined by an air-permeability apparatus,[4] was ground to a fineness of 13,000 sq. cm. per g., with a mortar and pestle. The same percentages by weight of cement of the coarse and reground Vinsol resin were mixed with separate portions of cement in a pebble mill for 1 hr. The results of determinations of chloroform-soluble material, methoxyl content of extract, and of the air content and flow of 1:3 concrete-sand mortars made with the cements are given in Table II.

TABLE II.—EFFECT OF SPECIFIC SURFACE ON THE AIR-ENTRAINING PROPERTIES OF VINSOL RESIN.

Vinsol Resin Added, per cent	Specific Surface of Vinsol Resin Added, sq. cm. per g.[a]	$CHCl_3$ Soluble Extract Found, per cent	Vinsol Resin Calculated from CH_3O, per cent	Air in Mortar, per cent	Flow, per cent
None.......	...	...	...	5.8	116
0.040.......	2 500	0.039	0.043	8.4	125
0.040.......	13 000	0.039	0.044	12.2	133

[a] The specific surface was determined by the air-permeability apparatus.

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[3] 1944 Book of A.S.T.M. Standards, Part II, p. 27.

[4] R. L. Blaine, "Studies of the Measurement of Specific Surface by Air Permeability," ASTM BULLETIN, No. 108, January, 1941, p. 17.

Experiments Using Rotary Calciner:

The following experiments were made in an effort to simulate more closely conditions obtaining in a cement plant than was done by oven heating of intermixed Vinsol resin and cement. Two cement clinkers were ground with gypsum and Vinsol resin in a steel rotary ball mill. Grinding was continued until the specific surface (Wagner turbidimeter) was between 1900 and 2000 sq. cm. per g. Cement A contained 0.14 per cent total alkalies expressed as Na_2O, while cement B contained 0.55 per cent. Samples of each cement were then subjected to heat for definite periods of time at several different temperatures in an electrically heated rotary calciner.[5] In this way the cement was constantly rolled and mixed, although not ground, while heating was taking place. After heating, the cement was analyzed for chloroform-soluble material and the methoxyl content of the chloroform extract determined. Air content and flow were determined on mortars made from the heat-treated cements.[6, 7]

In all cases in which the heating period was less than 6 hr. at temperatures of 200, 300, and 350 F., changes produced were practically insignificant. The heating was then increased to intervals from 7 to 48 hr., at temperatures of 200, 250, and 300 F. Results of such treatment are given in Table III.

When the samples were heated at 250 F. and above, steam was observed escaping for about 3 hr. through the opening which held the thermometer.

TABLE III.—EFFECT OF HEATING IN A ROTARY CALCINER ON TWO CEMENTS CONTAINING INTERGROUND VINSOL RESIN.

Heating Time, hr.	Temperature, deg. Fahr.	$CHCl_3$-Soluble Extract, per cent	CH_3O in Extract, per cent	Air in Mortar, per cent[a]	Flow, per cent
CEMENT A (0.14 PER CENT TOTAL ALKALI EXPRESSED AS Na_2O)					
Unheated....	...	0.020	3.54	18.9	103
48..........	200	0.011	2.17	19.0	97
48..........	250	0.016	1.49	18.6	96
7..........	300	0.013	3.18	19.6	100
18..........	300	0.009	1.73	16.6	88
30..........	300	0.013	0.98	15.0	76
48..........	300	0.006	0.75	13.3	70
CEMENT B (0.55 PER CENT TOTAL ALKALI EXPRESSED AS Na_2O)					
Unheated....	...	0.018	3.36	21.1	102
48..........	200	0.007	1.93	20.1	99
48..........	250	0.011	1.53	18.7	90
7..........	300	0.016	2.76	20.1	93
18..........	300	0.015	2.02	17.3	81
30..........	300	0.010	0.96	15.5	76
48..........	300	0.006	0.62	15.1	72

[a] Each value is the average of four determinations.

The data in Table III indicate that above certain limits increasing the temperature and time of heating cement containing interground Vinsol resin lowers its air-entraining properties. Cement A was unaffected by heating as long as 48 hr. at 250 F., but 18 hr. at 300 F. caused a significant reduction in air entrainment. Cement B appeared somewhat more sensitive, exhibiting a small reduction in air entrainment when heated at 250 F. for 48 hr. and a considerable reduction when heated at 300 F. for 18 hr. For each of the cements, there is a rough relationship between the air content and the CH_3O content for the 300 F. series. In general, the chloroform-soluble content and percentage of methoxyl in the extract are decreased. Figure 1 shows graphically the relationship between the percentage of methoxyl found in the chloroform extract and time of heating the cements at 300 F.

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[5] The rotary cylinder used was the same equipment as described by J. A. Murray in, "Experimental Electrical Rotary Calciner," *Chemical and Metallurgical Engineering*, Nov., 1927.

[6] A.S.T.M. Tentative Method of Test for Air Content of Portland-Cement Mortar (C 185–44 T), 1944 Book of A.S.T.M. Standards, Part II, p. 1227.

[7] Federal Specification for Portland Cement, SS-C-158a, p. 29.

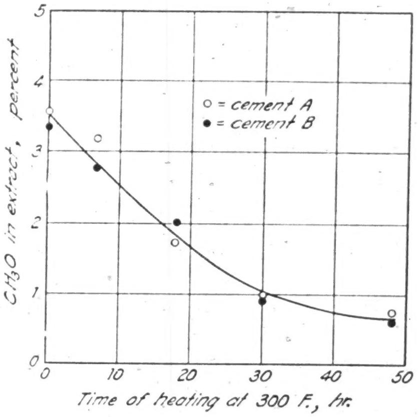

Fig. 1.—Relationship of Methoxyl Content of Chloroform Extract and Time of Heating Cement at 300 F.

DISCUSSION

In the manufacture of portland cement, the cement may be transferred from the ball mill to the silo with little loss of heat. Except in the case of mills having special cooling systems, the rate of cooling is very slow and frequently high temperatures may be found in the silos after many days. Experiments summarized in Tables I and III do not duplicate conditions found in a cement silo, but they do show that Vinsol resin is affected by temperatures exceeding 250 F. over extended periods of time. Furthermore they demonstrate that the air-entraining properties of cement containing the resin can be changed to a marked degree by such heat.

Several factors affecting results obtained by the methoxyl method are discussed in the paper by Bean and Peppler.[8] In using the methoxyl method, calculations are based on the assumption that the methoxyl content of the resin extracted by the chloroform-soluble method is constant (83.5 per cent recovery of 5.7 per cent CH_3O originally present in the resin before grinding and extracting). That such an assumption is not correct in the case of Vinsol resin cement which has been subjected to heating is shown clearly by the figures in Table III under the column marked "CH_3O in Extract." Figure 1 represents these values graphically and shows that the methoxyl content of the extract from heated cements is a function of the time and temperature of heating, and is not constant. Accordingly, the methoxyl method appears to be of little value as a means of measuring the amount of Vinsol resin present in cement so heated.

In correspondence with others interested in this problem it has been suggested that when cements containing Vinsol resin have been subjected to high temperatures during grinding, some of the resin may have polymerized at these temperatures to a material partially insoluble in chloroform, such cement still retaining most of its air-entraining properties. However, in Table III the data shown under the column heading "Air in Mortar" demonstrate that increased time of heating at 300 F. diminishes the air-entraining properties of the resin. It was further suggested that the polymerized resin (caused by heating) would probably be completely soluble in dichloroethylene and could thus be extracted from cement. The sample of cement A which had been heated for 48 hr. at 300 F., gave a chloroform-soluble extract of 0.006 per cent. When the same cement was extracted using dichloroethylene, 0.009 per cent of extract was obtained. The corresponding values for cement B heated 48 hr. at 300 F. were 0.006 per cent of chloroform extract and 0.011 per cent of dichloroethylene extract. This indicates that while the chloroform-soluble material in a Vinsol resin cement is considerably lowered by heating, more resin in some form is present than is indicated by the chloroform-soluble value. The results obtained by using either chloroform or dichloroethylene as a solvent indicate, however, that considerable resin is lost by prolonged heating of Vinsol resin cement at high temperatures.

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[8] Leonard Bean and R. B. Peppler, "Studies of Methods for Determination of Vinsol Resin in Cement," paper being prepared.

SUMMARY

Vinsol resin when heated in a beaker at 300 F. definitely carbonized. In 51 hr., about one-quarter of a 1-g. sample was lost by volatilization or oxidation. When cement containing interground Vinsol resin was heated at temperatures as high as 300 F. for periods as long as 48 hr., in a rotary mill, as much as two-thirds of the resin was lost as measured by the chloroform-soluble method. The methoxyl content of the residual resin was considerably reduced, and cement so treated had considerably less air-entraining properties than the same cement before heating. Dichloroethylene was found to extract more resin than did chloroform from Vinsol resin cements which had been subjected to considerable heat treatment.

Acknowledgments:

A considerable amount of the earlier work in this study was done by Milton Pollock. Julian Berch, Lillie Cook, Cyril Crocker, Richard Peppler, and Jeannette Williamson assisted in making analyses.

A COMPARISON OF ABSORPTION AND SOUNDNESS TESTS ON MAINE SANDS

By Andrew Adams[1] and Horace A. Pratt[2]

Synopsis

Tests on Maine sands indicate that soundness as determined by magnesium sulfate (Method C 88 - 41 T)[3] may be very closely estimated by the absorption test (Method C 128 - 42),[4] which can be completed in a much shorter time. Standard A.S.T.M. procedures were followed in obtaining the test results which were based on 62 sands well-distributed over the State. The soundness loss may also be predicted from the loss on the 14-mesh fraction alone, as indicated by their high correlation.

A study of the durability of Maine sands at the Maine Technology Experiment Station resulted in the making of many absorption and soundness tests during the past year. In addition to the standard tests, numerous other soundness tests were made on the 14-mesh fraction alone. In order to increase the number of sands to be tested at one time with the equipment available, studies were made to determine if the loss on one individual fraction could be substituted for the standard soundness test.

Of the four fractions used in these tests, the highest correlation with the standard soundness occurred in the case of the 8 and 14-mesh fractions, both being equally high. However, in many cases the laboratory samples lacked sufficient material retained on the No. 8 sieve; therefore, the 14-mesh fraction was selected for estimating the soundness of a sand.

It was realized also that more sands could be tested in a given period of time by means of the absorption test than by the soundness test. It requires 18 days to complete a soundness test when carried to complete drying at each cycle, but an absorption test can be made in 48 hr., only one ninth of that time.

Derivation of Data

The sands used in making the absorption and soundness tests came from sources well-distributed geographically over the State of Maine and varied mineralogically from wholly granitic (quartz and feldspar) sands to those containing large percentages of quartzite, schist, and shale. These sands did not contain an appreciable amount of limestone.

The absorption test was made in accordance with the A.S.T.M. Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 42).[4] Check tests were made on each sand, and the average value was used in comparing with the soundness test.

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[3] Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 41 T), 1942 Book of A.S.T.M. Standards, Part II, p. 1185.

[4] Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 42), 1944 Book of A.S.T.M. Standards, Part II, p. 445.

The soundness test was made in accordance with the Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 – 41 T).[3] Since the result of the soundness test is weighted according to the grading of the sand, a sieve analysis was first made on a 1000-g. sample, using Tyler sieves Nos. 4, 8, 14, 28, 48, and 100. After the fractions had been separated, as a result of the sieve analysis, samples weighing 100 g. were taken from each of the four required sizes and placed in separate baskets preparatory to immersion in the magnesium sulfate solution.

The magnesium sulfate, a commercial grade of epsom salt, was made into a saturated solution in the immersion tank well in advance of placing the sand samples in it. An excess of salt crystals was always present and the specific gravity was maintained between 1.296 and 1.308. The samples were immersed in the magnesium sulfate solution for 16 hr., following which they were drained and then placed in a drying oven that was maintained at a temperature between 105 and 110 C. The samples were dried to constant weight, cooled to room temperature, and again immersed in the solution. This procedure was repeated through five cycles, after which each sample was washed entirely free of the magnesium sulfate, dried to constant weight, and sieved over the same sieve on which it was originally retained.

From the weights of the material retained on these sieves, the actual percentages of loss were calculated for each fraction. These several percentages of loss, for the four fractions used for each sand, were weighted according to the grading of the sand and combined to give the total weighted percentage loss for the entire sand. The soundness test was made on 62 different sands in

TABLE I.—RESULTS OF ABSORPTION AND SOUNDNESS TESTS.

Sand	Grading, per cent		Absorption, per cent	Soundness		Estimated Soundness, Based on	
	P-48	P-100		14-mesh	Standard	14-mesh	Absorption
No. 4919	26	8	1.01	13.2	7.6	6.4	7.7
No. 4929	11	3	1.68	19.2	15.1	15.6	11.7
No. 4916	13	4	1.09	13.3	11.1	10.8	8.2
No. 4917	7	1	2.74	20.1	17.6	17.4	18.1
No. 4905	7	1	3.33	28.3	25.4	23.4	21.6
No. 4918	8	4	2.04	14.7	13.8	13.8	13.9
No. 4923	11	4	1.36	12.7	10.0	11.2	9.8
No. 4921	28	10	0.53	6.7	3.2	1.4	4.8
No. 4874	25	8	1.31	11.2	9.0	5.4	9.5
No. 4922	5	2	1.45	14.8	10.3	14.5	10.4
No. 1917	15	6	1.78	14.0	10.5	11.0	12.3
No. 1913	13	6	1.47	3.3	4.8	4.0	10.5
No. 4747	16	6	1.30	7.8	9.0	6.1	9.5
No. 1889	14	5	1.30	13.0	11.1	10.4	9.5
No. 1921	16	3	3.04	32.2	19.9	23.1	19.9
No. 2035	10	3	0.73	8.4	9.1	18.2	6.0
No. 4924	10	2	1.09	9.4	6.5	8.7	8.2
No. 4925	17	8	2.06	24.4	19.5	18.2	14.0
No. 4956	10	4	2.09	23.6	18.4	19.5	14.2
No. 4957	13	6	1.35	14.1	12.2	11.8	9.8
No. 447	16	4	0.81	13.4	10.4	9.7	6.5
No. 4920	14	4	0.96	13.4	9.2	10.5	7.4
No. 278	16	7	0.70	6.7	6.6	5.5	5.9
No. 342	21	7	0.72	9.4	8.3	5.4	6.0
No. 459	9	4	1.18	10.6	8.0	10.4	8.7
No. 382	22	5	0.73	8.0	5.4	3.6	6.0
No. 526	9	4	0.85	6.6	6.1	7.6	6.8
No. 158	14	6	1.16	12.5	8.2	10.3	8.6
No. 143	14	4	1.77	6.6	6.8	5.6	12.3
No. 511	15	7	0.70	3.5	5.0	3.6	5.9
No. 55	14	4	1.02	5.9	5.1	5.0	7.8
No. 135	10	4	2.25	17.9	17.2	15.3	15.2
No. 626	12	4	1.21	8.4	7.7	7.7	8.9
No. 496	18	7	1.38	18.0	13.9	9.7	9.9
No. 499	12	4	0.68	8.9	7.4	8.0	5.7
No. 579	10	6	1.44	21.7	17.5	18.6	10.3
No. 349	18	5	1.82	10.1	7.8	6.7	12.6
No. 592	18	6	0.89	13.3	11.3	9.3	7.0
No. 321	10	4	0.76	5.4	4.7	6.3	6.2
No. 138	10	5	1.25	6.5	5.6	7.3	9.2
No. 290	10	5	1.01	10.2	9.4	10.0	7.7
No. 458	17	6	0.67	6.6	4.9	4.8	5.7
No. 4	12	4	1.80	9.0	9.8	8.7	12.5
No. 182	15	4	0.49	4.5	3.1	3.6	4.6
No. 471	10	4	0.80	4.4	5.5	5.6	6.5
No. 421	21	5	0.74	7.3	5.2	3.5	6.1
No. 38	19	8	0.69	6.9	5.4	4.7	5.8
No. 250	11	4	0.79	5.6	4.1	6.0	6.4
No. 191	18	6	0.53	5.7	4.1	3.8	4.8
No. 122	10	4	1.44	5.8	6.3	6.6	10.3
No. 319	20	5	0.71	5.8	5.4	2.8	5.9
No. 239	24	6	0.32	4.0	2.3	0.1	3.6
No. 129	16	5	0.92	6.3	4.2	4.8	7.2
No. 285	10	4	0.68	7.2	5.9	7.6	5.7
No. 363	19	5	1.48	10.7	7.9	6.7	10.5
No. 809	21	7	1.17	16.2	9.2	10.4	8.7
No. 253	16	5	0.50	5.4	5.0	4.1	4.7
No. 435	13	5	0.82	13.2	9.8	11.0	6.6
No. 317	21	7	0.60	11.6	7.9	7.0	5.3
No. 464	11	6	1.36	9.1	8.6	9.0	9.8
No. 331	12	2	0.40	5.0	5.6	4.7	4.0
No. 799	11	4	2.15	8.0	6.8	7.8	14.6

this manner. Additional soundness tests were made on 86 other sands using only the 14-mesh fraction.

The soundness test results, based on 25 tests and check tests, checked 46 per cent closer when dried to constant weight than when dried for only 7 hr. at each cycle. In order to dry the samples to constant weight, especially the 48-mesh fraction, it was necessary for the samples to be in the drying oven at least 28 hr.

Table I shows the test results on which this study was based.

ANALYSIS OF RESULTS

The following simple correlation coefficients, each with its probable error, were obtained statistically from the test results of the soundness with magnesium sulfate, the absorption, and the grading on 62 sands:

Soundness *versus* per cent P-14
$r = -0.1806 \pm 0.0829$ Not significant
Soundness *versus* per cent P-48
$r = -0.3107 \pm 0.0774$ Significant
Soundness *versus* per cent P-100
$r = -0.3188 \pm 0.0770$ Significant
Soundness *versus* per cent absorption
$r = 0.8056 \pm 0.0301$ Highly significant
Soundness *versus* 14-mesh soundness
$r = 0.9469 \pm 0.0089$ Highly significant
Soundness *versus* fineness modulus
$r = 0.2411 \pm 0.0807$ Not significant

When the results are based on 62 sets of tests, a correlation coefficient below 0.250 is not significant. This means that there are 5 chances out of 100 that a value of 0.250 might be obtained wholly by chance, where no relationship actually exists between the variables. The significant values of the correlation coefficient lie between 0.250 and 0.325. Values within this range would be expected to occur from one to five times out of 100 by chance. Values greater than 0.325, which are highly significant, would be expected less than once in a hundred times by chance.

It will be noted that the two significant correlation coefficients for soundness with per cent P-48 and with per cent P-100 each have negative values. This means that as the amounts P-48 and P-100 increase, the soundness values decrease. The simple correlation coefficients for standard soundness with per cent absorption and standard soundness with 14-mesh soundness are both positive, which means that as the values for per cent absorption or 14-mesh soundness increase, the values for soundness will also increase.

The simple correlation coefficients were used statistically to derive the two following regression equations:[5]

$$\text{Estimated soundness} = 1.65 + 6.0010\,(\text{per cent absorption}) \ldots (1)$$

$$\text{Estimated soundness} = 0.95 + 0.7263(\text{14-mesh soundness}) \ldots (2)$$

The standard error of estimate resulting from the use of Eq. 1 is 2.8093, as compared with a standard deviation of 4.7027 for the entire group of soundness results. This result means that the range of soundness values corresponding to a given absorption value is only 59.7 per cent of the total range of soundness values. By the use of Eq. 1, then, we have controlled 40.3 per cent of the soundness variation. The standard error of estimate for Eq. 2 is 1.5248, or 32.4 per cent of the standard deviation. The control resulting from the use of Eq. 2 is 67.6 per cent.

The data were next examined to determine if the use of multiple regression equations might result in better control than in the case of the simple regression equations.

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[5] When one variable is plotted against another variable, as in Figs. 1 and 2, the resulting scatter diagram shows the relationship between them. The form of this relationship is indicated by the line which best fits these plotted points. This line is called the "line of regression," and the mathematical equation of this line of regression is termed the "regression equation." The measurement of the degree of association between the two variables is reduced to a relative basis by calculating the correlation coefficient which can range from zero, for no association at all, to plus or minus one for perfect relationship.

Multiple correlation coefficients and their probable errors were obtained as follows:

Soundness *versus*
  per cent P-100 (not significant)
  per cent absorption (highly significant)
    $R = 0.8211 \pm 0.0279$

Soundness *versus*
  per cent P-48 (not significant)
  per cent P-100 (not significant)
  per cent absorption (highly significant)
    $R = 0.8088 \pm 0.0296$

Soundness *versus*
  per cent P-100 (highly significant)
  14-mesh soundness (highly significant)
    $R = 0.9531 \pm 0.0078$

Soundness *versus*
  per cent P-48 (highly significant)
  per cent P-100 (significant)
  14-mesh soundness (highly significant)
    $R = 0.9796 \pm 0.0035$

The reader will undoubtedly have noticed the apparent discrepancy between the degrees of significance indicated for the two variables, per cent P-48 and per cent P-100, in connection with these multiple correlation coefficients and those for the corresponding simple correlation coefficients listed previously. The following explanation is offered. When these two variables were compared separately with soundness, the value of the resulting simple correlation coefficients indicated that the degree of association, or the relationship, between them was great enough in each case to be designated significant. These simple correlation coefficients measured the apparent relationship between the variables concerned without regard to any possible influences by other variables which might be associated with soundness. On the other hand, the multiple correlation coefficients presented above indicate the joint relationship between soundness and two or three other variables. The relative effect of each variable upon soundness, as indicated by the degree of significance shown above, was determined statistically from a study of the standard partial regression coefficients and was checked by deriving the partial correlation coefficient in each case. This method shows the degree of relationship which exists between soundness and each independent variable when allowance is made for the effects of their common associations with the other variables. Thus, when the data were classified according to per cent absorption, the effects upon soundness of the percentages passing the No. 48 and the No. 100 sieves were each found to be "not significant." On the other hand, when classified according to the 14-mesh soundness results, the effects of these same two variables upon soundness would be termed "highly significant."

These results show that the grading of a sand is not significant when used statistically with the results of the absorption test for estimating the soundness, but the grading is highly significant for prediction purposes when used with the results of the 14-mesh soundness. Therefore, based on grading and 14-mesh soundness, the following multiple regression equation was derived:

$$\text{Estimated Soundness} = 4.24 - 0.3131\ (\text{per cent P-48}) + 0.2305\ (\text{per cent P-100}) + 0.7245\ (\text{14-mesh soundness}) \quad (3)$$

The standard error of estimate resulting from the use of Eq. 3 is 0.9683, or only 20.6 per cent of the standard deviation. This means that the range of soundness values, which would be predicted by this equation, is only 20.6 per cent of the total range. The variation controlled is, therefore, 79.4 per cent.

Figure 1, a scatter diagram, indicates the relationship between the standard soundness and the loss of the 14-mesh fraction. It will be noted that the plotted points are arranged in very nearly a straight line diagonally downward across the diagram. The narrowness of this band of points indicates that the two variables are very closely related. From this scatter diagram, a numerical measure of the relationship between the two variables was obtained by calculating the correlation coefficient, *r*, according to the method described by H. Walter Leavitt.[6] As would be expected from the location of the points on the scatter diagram, a very high correlation coefficient ($r = 0.9469 \pm 0.0089$) was obtained. The fact that this coefficient is positive indicates a direct relationship between the variables; that is, as the value of one variable increases, the value of the other also increases.

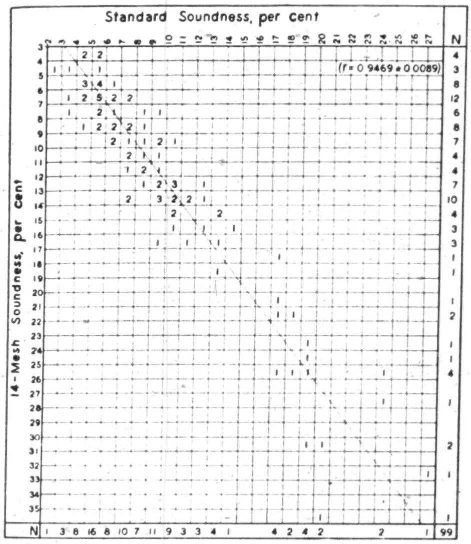

FIG. 1.—Scatter Diagram—14-Mesh Soundness *versus* Standard Soundness.

The close relationship between the two variables, as indicated both by the narrowness of the band of plotted points in the scatter diagram and by the magnitude of the correlation coefficient, shows that the soundness of a sand with magnesium sulfate may be estimated very closely from the loss of the 14-mesh fraction.

Figure 2, a scatter diagram, shows the relationship between the absorption of sands and the soundness. This diagram shows a fairly well-defined band of points ranging from the upper left corner to the lower right corner. As the per cent absorption increases, the soundness loss increases, indicating a positive relationship. The highly significant correlation coefficient ($r = 0.8056 \pm 0.0301$) means that the soundness of a sand may be estimated very closely from the absorption test.

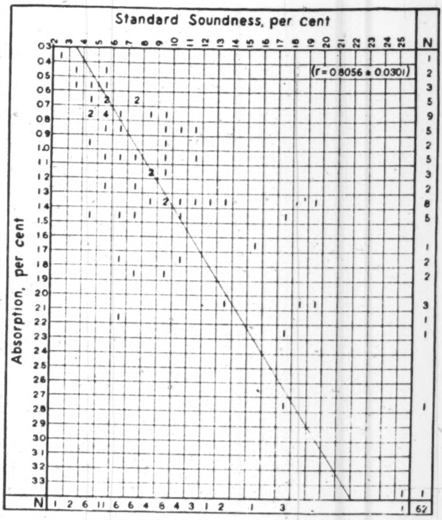

FIG. 2.—Scatter Diagram—Absorption *versus* Standard Soundness.

CONCLUSIONS

The conclusions derived from this study of absorption and soundness of Maine sands may be summarized as follows:

1. The absorption test can be completed in about one ninth of the time required to complete a soundness test when the samples are dried to constant weight.

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[6] H. Walter Leavitt, "A Method of Evaluating Concrete Data by Correlation," ASTM BULLETIN, No. 91, March, 1938, p. 15; or *Maine Technology Experiment Station, Paper No. 22*, March, 1938.

2. Drying the sand samples to constant weight results in fairly close check tests, 46 per cent closer than when dried for only seven hours.

3. The relationship between the soundness and absorption tests is highly significant, as shown by the correlation coefficient, ($r = 0.8056 \pm 0.0301$).

4. The soundness of a sand with magnesium sulfate may be estimated very closely from the absorption test.

5. The high relationship between the soundness and absorption tests indicates that both tests measure similar characteristics of a sand.

6. The relationship between the soundness of a sand and the soundness of the 14-mesh fraction is extremely high, the correlation coefficient being 0.9469 ± 0.0089.

7. The soundness of a sand may be estimated very closely from the soundness loss of the 14-mesh fraction.

8. Taking into consideration both the significant and highly significant correlation coefficients, the soundness may be estimated by means of any one of the three following equations:

$$\text{Soundness} = 1.65 + 6.0010\ (\text{per cent absorption}) \quad (1)$$

$$\text{Soundness} = 0.95 + 0.7263\ (\text{14-mesh soundness}) \quad (2)$$

$$\text{Soundness} = 4.24 - 0.3131\ (\text{per cent P-48}) + 0.2305\ (\text{per cent P-100}) + 0.7245\ (\text{soundness loss on 14-mesh fraction}) \quad (3)$$

STRESS CONDITIONS FOR THE FAILURE OF SATURATED CONCRETE AND ROCK

BY K. TERZAGHI[1]

SCOPE OF INVESTIGATION

This paper deals with the stress conditions for the failure of saturated concrete and rock.[2] The water which occupies the voids is assumed to be under pressure. In practice such a condition prevails in the water which percolates through the concrete of a gravity dam and the rock located beneath the dam. In the laboratory the stress conditions for the failure of such materials could be investigated by means of the test arrangement shown in Fig. 1. A cylindrical specimen, covered with a watertight membrane, is immersed in water under pressure p_c. The specimen is completely saturated with water, and the pore water communicates through the voids of a porous stone with water under a pressure u_w. The pressure u_w is smaller than p_c. It can be expressed by an equation

$$u_w = p_c - \bar{p}_c$$

wherein $\bar{p}_c$ represents the difference between the total confining pressure and the pore water pressure. To the all-around pressure p_c a *unidimensional*[3] pressure q per unit of area is added, and this pressure is increased until the specimen fails. The value of q at failure will be referred to as the *confined compressive strength*, q_c.

Since it would be rather difficult to carry out the test illustrated by Fig. 1, an attempt will be made to evaluate q_c on a semi-empirical basis. No attempt of this kind has any prospects for success unless the details of the processes which lead to failure are clearly understood. Therefore the investigation will be carried out in the following steps which proceed from relatively simple to more complex conditions:

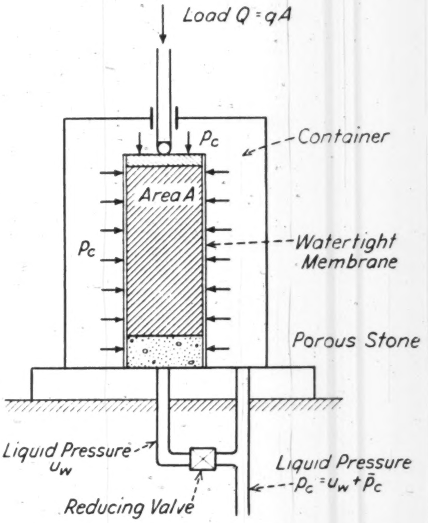

FIG. 1.—Test Arrangement for Determining Influence of Pore Water Pressure on Confined Compressive Strength.

(*a*) Investigation of the mechanical causes of the failure of concrete and rock with empty voids, under unidimensional compression, q per unit of area.

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[2] In this paper the term rock refers only to quasi-isotropic (statistically isotropic) rocks of sedimentary or igneous origin. Schists and amorphous rocks are beyond its scope.

[3] The term unidimensional pressure indicates in contrast to the three-dimensional all-around pressure p_c a pressure which acts parallel to a line.

(*b*) Investigation of the effect of a confining pressure p_c on the strength q_c of specimens with empty voids.

(*c*) Investigation of the corresponding effect of a confining pressure exerted by a liquid under a pressure u_w which permeates the voids of the specimen.

(*d*) Investigation of the effect of a confining pressure p_c on the strength of a specimen in which the voids are filled with a liquid under pressure $u_w < p_c$.

Thus the problem will be solved step by step until all the data required for drawing the final conclusions are assembled.

The unidimensional pressure q per unit of area which is superimposed upon the confining pressure p_c will briefly be called the unit load. The term normal stress, indicated by σ, represents the normal component of the force which acts on a plane section through a specimen divided by the entire area of this section. Hence the value σ represents the average pressure on the section. The normal stress on any section through a specimen immersed in a liquid under pressure p_c is $\sigma = p_c$. If the voids are empty, the entire stress σ is carried by the solid. If they are filled with water, part of it may be carried by the water.

TYPES AND CAUSES OF FAILURE UNDER UNIDIMENSIONAL COMPRESSION

Experience shows that axially loaded cylindrical specimens fail either by general disintegration or else by separation along one or several surfaces of fracture. These surfaces may intersect the direction of the load at any angle between 0 deg. and about 30 deg. as shown in Fig. 2. The failures along planes in the direction of the load will be referred to as *splitting failures*. A failure by sliding along a plane intermediate between a splitting and a shear plane will be called a *failure by pseudo shear* because it involves simultaneous splitting and shearing.

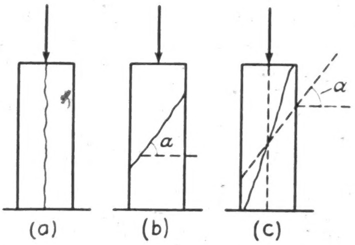

FIG. 2.—Types of Failure.
(*a*) Splitting. (*b*) Shear failure. (*c*) Pseudo-shear.

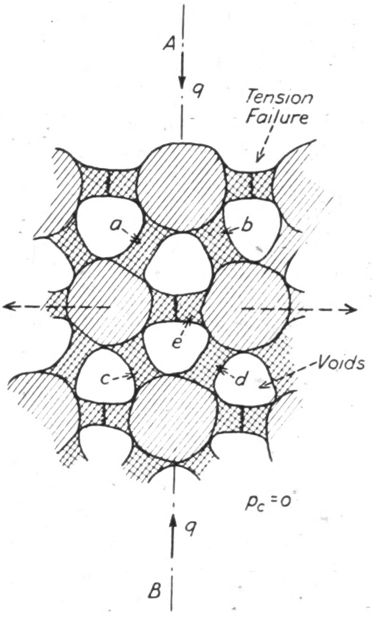

FIG. 3.—Diagrammatic Representation of the Mechanics of Splitting Failures.

Failure by splitting seems to be due to an intergranular wedge action. This process is illustrated by Fig. 3, which shows a section through a fragment of a porous, quasi-isotropic material. The material consists of rounded particles which are inter-connected by solid bonds such as *a*, *b*, *c*, *d* and *e*. A vertical pressure tends to destroy the bonds *a*, *b*, *c* and *d* by bending or shear, and that at *e* by tension. If such a material fails by splitting, we are obliged to assume that the failure in the bonds subject to tension preceded failure in the others. In accordance with the definition of the term stress, the normal stress on the section *A–B* through the specimen is equal to zero. Yet, at the bonds oriented like that at *e*, the tension can become large enough to cause failure.

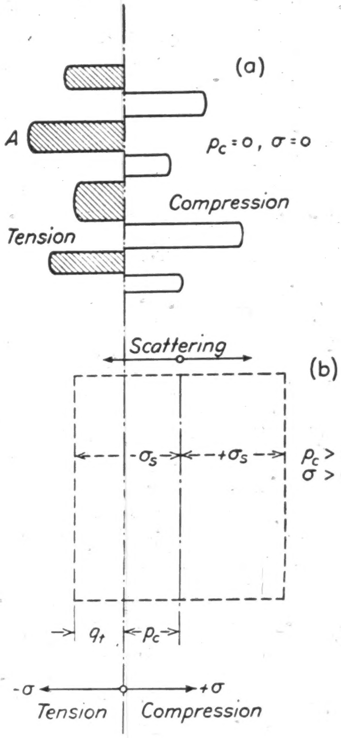

FIG. 4.—(*a*) Real Distribution of Stresses on Potential Surface of Splitting of Dry Specimen Under Unidimensional Pressure. (*b*) State of Stress on Surface of Splitting of Dry Specimen Under Triaxial Compression, at Instant of Failure.

The mechanics of the splitting failure of a specimen of a quasi-isotropic, crystalline material subject to unidimensional compression are illustrated by Fig. 4(*a*) which represents a vertical section through part of the surface of failure. The average normal stress on this surface is equal to zero. But since the material is only statistically isotropic, the normal stress is only statistically equal to zero. By dividing all the negative forces which act on the section by one half of the total area of the section, the negative scatter stress $-\sigma_s$ is obtained. The positive scatter stress $+\sigma_s$ represents the compression force per unit of area of the other half. Since the average stress is equal to zero, the two scatter stresses must be equal and opposite. If the average stress on a section is σ, approximately one half of the section is acted upon by an average stress of about $\sigma - \sigma_s$ and the balance by $\sigma + \sigma_s$.

Failure by splitting starts as soon as the maximum scatter stress (abscissa of the peak *A* on the left-hand side of Fig. 4(*a*)) becomes equal to the real tensile strength of the material. This maximum scatter stress is considerably greater than the average. However, since the tensile strength is customarily defined as the average force per unit of the total cross-sectional area at which the specimen fails, the splitting stress at failure is also taken as the total force which produces the splitting failure divided by the area on which this force acts (one half of the total area of the splitting plane, including the voids).

Failure by splitting is not strictly comparable to failure by pure tension because the mutual displacement of the individual constituents which precedes these two types of failure is somewhat different. However, owing to the absence of reliable information concerning the mechanical effect of this difference, it will be assumed that the specimen fails by splitting as soon as the scatter stress $-\sigma_s$ becomes equal to the tensile strength q_t of the material. Since the failure is exclusively produced by the scatter stress $-\sigma_s$, this stress will be referred to as *splitting stress.* If the average normal stress on a potential surface of splitting is σ, the specimen does not split until the splitting stress becomes equal to

$$\sigma_s = \sigma + q_t \dots\dots\dots (1)$$

In contrast to a pure splitting failure, a pure shear failure depends not on the scattering of a stress from the average stress but on the average itself. Hence in contrast to the splitting failure, the shear failure of quasi-isotropic materials is governed by the same laws as the shear failure of really isotropic materials, but it is very doubtful whether any quasi-isotropic material fails in this manner except under very high effective confining pressure.

EFFECT OF CONFINING PRESSURE ON STRENGTH OF SPECIMENS WITH EMPTY VOIDS

The influence of a confining pressure p_c on the strength q_c of specimens with empty voids can readily be investigated by means of triaxial compression tests on dry specimens protected by a watertight membrane. Tests of this type have been made by von Kármán (**5**)[4] on marble, Richart, Brandtzaeg, and Brown (**9**) on concrete, and by Roš and Eichinger (**10**) on concrete, marble, and several other materials. All these tests demonstrated that the strength q_c of concrete and rocks increases rapidly with increasing values of the confining pressure, as indicated in Fig. 5(*a*) and 5(*b*). Figure 5(*a*) represents the test results for porcelain and Fig. 5(*b*) for marble and concrete. For concrete, Richart obtained the approximate empirical relation

$$q_c = q_u + 4.1\, p_c \dots\dots\dots (2)$$

wherein q_u is the unconfined compressive strength of the concrete commonly referred to as *standard compressive strength.*

The oldest and most commonly accepted theory of the influence of the confining pressure on strength is Mohr's theory. It is based on the tacit assumption that the scatter stresses are equal to zero. Hence the theory is unable to account for failures by pseudo shear and by splitting. Furthermore, according to Mohr's theory, the shearing resistance of the material is equal to

$$s = c + \sigma f(\sigma)$$

wherein c is an empirical constant called the cohesion, σ the normal stress on the section, and $f(\sigma)$ an empirical function of σ. The value c (shearing resistance for $\sigma = 0$) is assumed to be a constant for each material and independent of the stress history. In reality, the shearing strength c of some materials such as neat

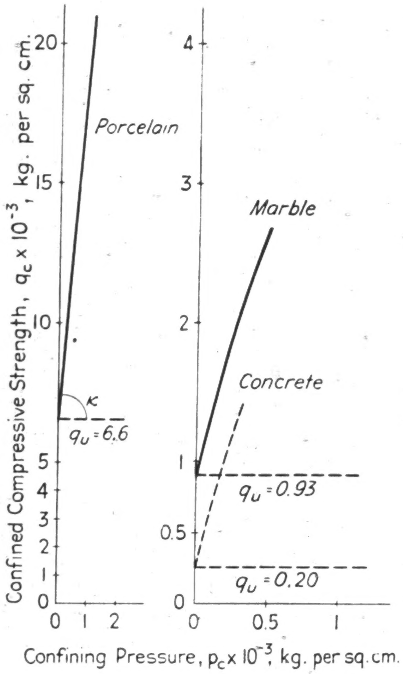

FIG. 5.—Relation Between Confining Pressure and Confined Compressive Strength for Porcelain, Marble, and Concrete.

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[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 791.

cement is very considerably and permanently increased by the temporary application of a high, confining pressure whereas the shearing strength of others may be reduced or even destroyed. This fact constitutes a second discrepancy between Mohr's theory and reality. Nevertheless, the theory serves a useful purpose because, in spite of its simplicity, it gives at least an approximate conception of the stress conditions for the failure of quasi-isotropic materials such as rocks. With little or no confining pressure, the position of the surfaces of failure may be very different from what Mohr's theory would lead us to expect. But with increasing confining pressures, the errors become less and less important, because, for reasons to be discussed below, the type of failure approaches more and more that of a pure shear failure.

It is always of considerable interest to know the structural changes which lead to the failure of a material. The mere fact that a surface of failure intersects the direction of the largest principal stress at a given angle does not indicate to what extent the scatter stresses participated in producing the failure. But if the test results are graphically represented by Mohr's circles, the slope angle of the potential surfaces of pure shear can be derived from Mohr's diagram, by means of a well-known graphical procedure. By comparing the angle thus obtained with that of the real surfaces of failure, the importance of the deviation of the type of failure from one due to pure shear can be ascertained.

More recently Brandtzaeg has conceived a theory which takes the phenomenon of splitting into consideration (Richart *et al.* (9)). The theory accounts remarkably well for the transition of quasi-isotropic materials from the elastic into the plastic state and various other phenomena, but it disregards the existence of voids. Therefore it is unsuitable as a basis for investigating the influence of the pore water pressure on strength. In order to investigate this influence, it is necessary to take the real structure of the material into consideration and to analyze the real causes of failure.

In spite of its apparent complexity, the failure of every quasi-isotropic, granular material can be resolved into one or more of the following four components:

1. Failure by tension in the bond between grains.
2. Failure by tension within grains.
3. Failure by shear in the bond between grains.
4. Failure by shear across grains.

The results of compression tests on a considerable number of quasi-isotropic, nonmetallic materials including marble and cement mortar have shown that the failure of these materials at low confining pressures is primarily due to tension and shear between grains (pseudo-shear failure, 1. + 3.). With increasing confining pressure, the shear across grains becomes more and more frequent (failure types 1. + 3. + 4.) and at very high confining pressures, the shear occurs almost exclusively within the grains (type 4) (Roš (10)).

If a material such as porcelain fails only by splitting, the slope angle κ of the q_c—p_c line in Fig. 5(*a*) can easily be determined. The procedure is illustrated by Fig. 4(*b*). The figure shows a vertical section through the potential surface of splitting. If the specimen is acted upon by a confining pressure p_c, the normal stress σ on this surface is equal to p_c. Failure by splitting requires (Eq. 1) the splitting stress σ_s to become equal to the sum of the normal stress $\sigma = p_c$ and the tensile strength q_t of the material,

$$\sigma_s = p_c + q_t \dots\dots\dots (3)$$

The splitting stress σ_s is due to the action of wedges driven by the unidimensional excess pressure q_c which causes the failure. Therefore, it seems reasonable to assume that the splitting stress σ_s increases in direct proportion to q_c. At $p_c = 0$, q_c is equal to q_u, and $\sigma_s = q_t$. Since σ_s can be assumed to increase in direct proportion to q_c, we can write

$$\sigma_s = q_t \cdot \frac{q_c}{q_u} \quad \ldots\ldots\ldots (3a)$$

Combining Eq. 3 with Eq. 3a we obtain

$$q_c = q_u\left(1 + \frac{p_c}{q_t}\right) = q_u + p_c \frac{q_u}{q_t} \quad \ldots (4)$$

The slope angle κ of the corresponding q_c—p_c line in Fig. 5(*a*) is determined by the equation

$$\tan \kappa = \frac{q_u}{q_t}$$

wherein q_u is the standard compressive and q_t the standard tensile strength of the material. This equation was published by Roš (**10**). He found it to be in remarkable agreement with the results of his triaxial compression tests on porcelain. Porcelain seems to be the only material which is known to fail solely by splitting. The ratio q_u/q_t for the tested specimens was equal to 14.5 which is unusually high. Under uniaxial compression, the specimens failed by pure splitting along one or two surfaces. Under triaxial compression, they broke up quite suddenly into numerous splinters whose longest dimension was oriented parallel to the direction of the pressure on the specimens. For porcelain, the value q_c, Eq. 4, is equal to

q_c(kg. per sq. cm.)

$$= 6550\left(1 + \frac{p_c}{457}\right) \quad \ldots (5)$$

The highest confining pressure p_c which was applied during the tests was 1000 kg. per sq. cm., corresponding to a value $q_c = 21{,}200$ kg. per sq. cm. However, at a pressure of 15,700 kg. per sq. cm., the top bearing plate failed, whereupon the test had to be discontinued.

Concrete and most rocks fail by pseudo-shear rather than by pure splitting. Hence, the influence of the confining pressure on the shearing resistance of these materials must also be taken into consideration. Experience has shown that the resistance against shear across a mineral grain at pressures of less than several hundred atmospheres is practically independent of the normal stress on the shear plane (Polanyi (**8**), Sachs (**12**), Griggs (**3**)). Therefore, the observed rapid increase of the shearing resistance due to an increase of the confining pressure indicates that the failure is due chiefly to a failure of the connection between the grains. The corresponding surface of sliding is uneven, as indicated in Fig. 6(*a*). If the material located above the surface of sliding moves towards the right, the intergranular connections located on the right-hand slopes of the humps fail by tension and the others by shear. The force required to rupture the connections by tension is likely to be considerably smaller than the

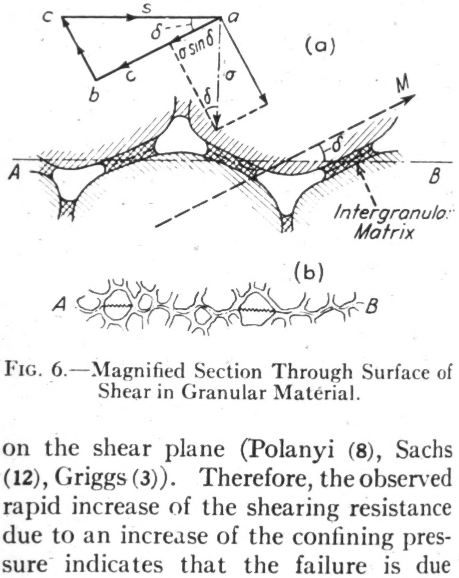

FIG. 6.—Magnified Section Through Surface of Shear in Granular Material.

force required to break them by shear. Therefore the connections on the right-hand slopes of the humps will be disregarded. Whatever the details of the intergranular connections and the porosity of the intergranular boundary zones may be, the direction of the movement associated with the failure rises at some angle δ to the plane A–B as indicated in Fig. 6(a) by the arrow M. The force required to sever the solid connections between the grains is c per unit of area of A–B. It is assumed to be independent of stress. Since A–B is acted upon by a normal stress σ per unit of area, the shearing stress s required to sever the connections and to produce a displacement in the direction of the arrow M can be determined by means of the polygon of forces a-b-c shown in Fig. 6(a). It is equal to

$$s = (c + \sigma \sin \delta) \frac{1}{\cos \delta}$$

$$= \frac{c}{\cos \delta} + \sigma \tan \delta$$

The normal stress σ is equal to the sum of the confining pressure p_c and the supplementary stress σ_q produced by the unidimensional pressure q which is superimposed on the confining pressure, whence

$$s = \frac{c}{\cos \delta} + (p_c + \sigma_q) \tan \delta \quad ..(6)$$

In Fig. 6(a) all the humps are shown to be similar to each other. In reality some of them have gentle slopes and others steep ones, as indicated in Fig. 6(b). Here and there a grain will be twisted out of its seat by rotation. The humps with the steepest slopes will fail by shear across the hump, and the resistance against such a failure is independent of the normal stress. But the majority of the humps will be overridden, and it is the displacement along the slopes of these gentle humps which causes the deviation of the direction of the movement from that of A–B.[5]

If the area occupied by the intergranular connections in Fig. 6(a) is very small compared to the total surface of the intergranular boundaries, two factors tend to produce an additional increase of the unit shearing resistance s. First of all, even a small confining pressure acting on a confined specimen produces a high concentration of pressure on the intergranular matrix. At low pressures the shearing resistance of this matrix is probably independent of the pressure. But at very high pressure the shearing resistance of every solid which has been tested up to this time increases rapidly with increasing pressure (Bridgman (1)). Second, the confining pressure p_c produces new contacts between the grains which did not exist before p_c was applied. At the new contacts, the slippage is resisted by the frictional resistance which must be added to the shearing resistance of the intergranular connections. If f is the coefficient of friction of grain on grain, the greatest value which the frictional resistance can assume per unit of area of the surface of sliding is σf. It increases the shearing resistance on the rough surface by

$$s_f = \sigma \frac{f}{\cos \delta} = (p_c + \sigma_q) \frac{f}{\cos \delta}$$

The total unit shearing resistance s_1 is at least equal to the sum of s_f and s, Eq. 6

$$s_1 = s + s_f$$

$$= \frac{c}{\cos \delta} + (p_c + \sigma_q)\left(\tan \delta + \frac{f}{\cos \delta}\right)$$

On any rough surface of sliding, the

---

[5] If a rock contains anisotropic crystals, a shearing stress of long duration may cause these crystals to rotate very slowly until their cleavage planes coincide with the shear plane. However, this paper deals only with stresses of short duration.

resistance against overriding the humps increases with increasing values of the normal stress $\sigma = p_c + \sigma_q$ whereas the resistance against shear across the grains is nearly independent of the normal stress. With increasing pressure an increasing percentage of the total area of shear cuts across grains. Therefore, the rate of increase of the shearing resistance decreases with increasing normal pressure.

EFFECT OF PORE WATER PRESSURE ON STRENGTH

The preceding discussions have left no doubt that the increase in strength due to the increase of the confining pressure p_c on specimens with empty voids is chiefly due to the fact that the grains themselves are very much stronger than the bond between the grains. Otherwise the failure would take place across the grains, and, as a consequence, the strength would be practically independent of the confining pressure. As a matter of fact, the strength of steel, which fails only across the grains, decreases slightly with increasing confining pressure instead of increasing (Roš (11)).

It has also become evident that the strength of the specimens depends on the pressure which is carried by the bond between grains along the potential surfaces of failure. The state of stress in the grains is irrelevant. If the voids of the specimen are empty, the normal stress due to a confining pressure p_c is entirely carried by the solid material which constitutes the bond. An invasion of the voids by a liquid under pressure p_c does not alter the stress, but it reduces that part of the stress p_c which is carried by the bond. Therefore it reduces the strength. The magnitude of the decrease depends on the degree of continuity of the intergranular bond. This degree can be expressed by the ratio of that part of the area of the potential surface of failure which is in contact with the interstitial liquid and the total area of this surface. It will be referred to as *boundary porosity*, n_b.

The data required for estimating the boundary porosity can be obtained by means of compression tests on saturated specimens with unprotected surface, immersed in a liquid under pressure p_c. Figure 7(a) represents a section through a completely saturated specimen surrounded with and permeated by water under a pressure p_c. While the water pressure rises from zero to p_c, the density of the water increases more than the density of the solid. Hence, water flows into the voids. However, since the total volume decrease of the water is very small, the water pressure in the interior of the specimen becomes equal to p_c a short time after the external pressure has assumed this value (Fig. 7(b)). In a specimen saturated with oil the stress adjustment takes place much more slowly than in a specimen saturated with water. Therefore water is preferable to oil.

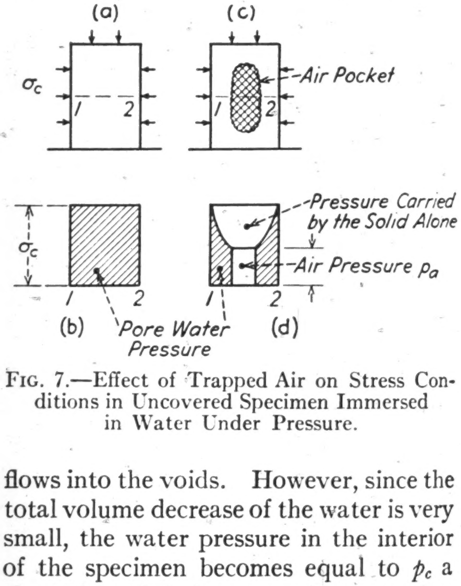

FIG. 7.—Effect of Trapped Air on Stress Conditions in Uncovered Specimen Immersed in Water Under Pressure.

If the specimen contains air (Fig. 7(c)), a large quantity of water must enter the voids of the specimen until the pressure in the air becomes equal to the external fluid pressure. Figure 7(d) shows the state of stress while the volume of the air is still decreasing. Since the pressure p_a in the air is not known, the state of stress illustrated by Fig. 7(*d*) precludes a correct interpretation of the test results. The transition from the state illustrated by Fig. 7(*d*) to that illustrated by Fig. 7(*b*) may require weeks or months.

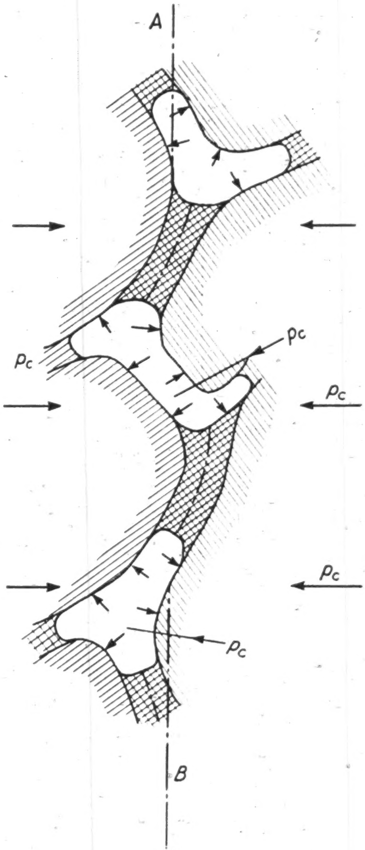

FIG. 8.—Magnified Section Through Surface of Splitting in Uncovered Specimen of Granular Material Immersed in Liquid Under Pressure p_c.

To make sure that the test specimen does not contain more than a trace of air, the specimen should be dried at 105 C. prior to the test and then saturated under vacuum. The success of this operation can be checked by keeping the specimen under liquid pressure p_c for one or two days while all valves are closed. If the specimen contains an appreciable volume of air under a pressure of less than p_c, the pressure in the liquid will drop because the volume occupied by the air is still decreasing. Any departure from the procedure recommended in this paragraph may preclude the possibility of correct interpretation of the test results.

The effect of the presence of water under pressure in the voids on the strength of porous materials which fail only by splitting is illustrated by Fig. 8. If the voids of the specimen were empty, a confining pressure p_c would increase the strength of the specimen from the standard strength q_u to the confined compressive strength q_c, Eq. 4. As explained before, the increase in strength is due to the fact that the confining pressure forces the two halves of the specimen together with a force p_c per unit of area of the total surface. If the voids of the specimen are filled with a liquid under pressure p_c, the pressure which is transmitted from right to left from solid to solid is not p_c as in jacketed specimens but only $p_c\ (1 - n_b)$. Hence, in order to compute the compressive strength q'_c of specimens without a jacket, one must replace p_c in Eq. 4 by $p_c\ (1 - n_b)$ whence

$$q'_c = q_u\left[1 + \frac{p_c(1 - n_b)}{q_t}\right] \quad . . (7)$$

Solving for n_b we obtain

$$n_b = 1 - \frac{q_t}{p_c} \times \frac{q'_c - q_u}{q_u} \quad . . . . (8)$$

This equation would make it possible to compute the boundary porosity of materials, such as porcelain, which fail only by splitting, but so far only jacketed specimens of such materials have been tested.

Most materials fail by pseudo-shear along surfaces of sliding. If the interstices along the surface of sliding represented by Fig. 6(a) are filled with a liquid under a pressure p_c, the normal pressure which presses the sliding part of the specimen onto its uneven seat is equal to $p_c\ (1 - n_b)$ per unit of area. Hence Eq. 6 must be replaced by

$$s' = \frac{c}{\cos \delta} + [p_c(1 - n_b) + \sigma_q] \tan \delta \ldots (9)$$

Triaxial compression tests on specimens without jacket have been made only on concrete (Terzaghi (13)) and on Solenhofen limestone and marble (Griggs (3)). Both series of tests have shown that fluid pressures up to several hundred atmospheres have no measurable effect on the compressive strength of these materials, whereas equal pressures acting on jacketed specimens increase q_c very considerably. To account for the test results, it is necessary to assume that the value of n_b in Eq. 9 is almost equal to unity. In other words, the area of actual contact or merging between the individual grains could not have exceeded a small fraction of the total intergranular boundaries. Yet, since the volume porosity of both materials is very low, the voids must consist of very narrow, but continuous slits.

The presence of a continuous network of slits in crystalline and in clastic rocks in general is also suggested by the striking influence of drying on the compressive strength of rocks. Complete statistics regarding this influence are not yet available, but it has repeatedly been observed that the immersion of dry rock specimens, including specimens of granite and other igneous rocks with a very low volume porosity, reduces their compressive strength by amounts up to 10 per cent, in exceptional cases even by 20 per cent.[6] There are no known rock constituents which decrease in strength upon contact with water. Therefore the loss of strength can only be due to one of the two following conditions. Part of the intercrystalline matrix consists of soluble material which goes into solution when the dry rock is immersed, whereby the intercrystalline connections are weakened, or else part of the strength of the rock is due to the surface tension in that part of the interstitial liquid which does not evaporate at room temperature. Immersion eliminates this source of strength as it eliminates the entire strength of a dry clay. If the boundary porosity n_b were equal to or only slightly greater than the volume porosity n (tubular or pocket-shaped voids), neither one of these two conditions could possibly account for a measurable loss of strength due to immersion. On the other hand, if the boundary porosity is close to unity, either one of the two processes could account for the observed phenomena. Hence the effect of drying on the compressive strength also indicates that the value of n_b is close to unity.

WIDTH OF THE VOIDS IN CRYSTALLINE ROCKS

If the results of compression tests on specimens with and without jacket indicate that the boundary porosity n_b is close to unity, whereas the volume porosity n is very much smaller, the voids must consist of narrow slits with an average width d. The width d can be estimated by dividing the volume porosity n by the estimated area a of the intergranular boundaries per unit of volume,

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[6] The effect of immersion on strength is commonly expressed by the ratio between the compressive strength of the saturated and the dry specimens. It is called the *coefficient of softening* η. A. Hanisch obtained for 11 different granites from Austria (cube strength in a dry state q_d = 1070 to 1923, average 1482 kg. per sq. cm.) values of η between 0.74 and 0.98, average 0.88. For nine crystalline limestones from Austria, q_d = 618 to 1417, average 981 kg. per sq. cm., he found η = 0.84 to 0.96, average 0.90. M. Gary tested 25 different granites from Sweden and Germany, q_d = 1163 to 3519, average 2440 kg. per sq. cm. and found η = 0.82 to 0.99, average 0.94. (More complete data can be found in a book by Hirschwald (4)).

$$d = \frac{n}{a}$$

If D is the average grain diameter, a is roughly equal to $3/D$.

The porosity of crystalline rocks averages 0.02. If the average diameter of the mineral constitutents ranges between 1 mm. and 3 mm., the corresponding values of d are between about 7 μ and 20 μ.

An independent estimate can be made by determining the coefficient of permeability k of the porous material; estimating the length L of the intergranular boundaries per unit of area of plane sections which is roughly equal to $2/D$; establishing the equation for the rate of laminary flow through slits with a width d and a breadth L, and solving for d. However, reliable data regarding the permeability of rocks and other pseudo-isotropic materials are still very scarce.

Some information concerning the permeability of rocks was published by Kessler and Sligh (6). Trial computations based on these data show quite consistently that the values of d computed on the basis of permeability are much smaller than those estimated on the basis of the volume porosity. This discrepancy suggests that the experimental values of k are much too low. As a matter of fact, considering the method of testing, important errors seem to be quite inevitable. The tests were made by letting the water percolate under a pressure of 100 psi. through plate-shaped specimens with a thickness of 0.5 in. The plates were obtained by sawing or cutting. During these processes the surface pores became filled with rock dust. Subsequent flooding of the top of the plates with water under high pressure inevitably drove the dust still deeper into the pores and clogged the entrance to the channels. The loss of head due to percolation across this filter skin is likely to have been many times greater than the loss of head due to flow through the unobstructed part of the void system. The resulting error could have been eliminated by the test arrangement illustrated by Fig. 9. The cylindrical specimen, with a cross-section area A, is surrounded by a cylinder with thick walls and the clearance between the specimen and the walls is sealed by a bituminous matrix. G_1 and G_2 represent two pressure gages. The gages are connected by tubes and horizontal bores, B_1 and B_2, with the interior of the specimen. The upper end of the specimen is covered with water under pressure u. The discharge is Q per unit of time or

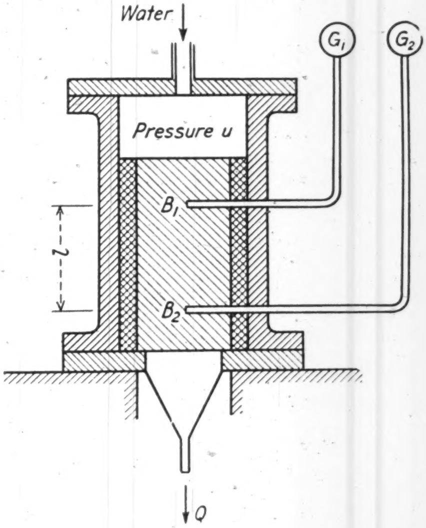

FIG. 9.—Apparatus for Determining the Coefficient of Permeability of Rock Specimens.

$$v = \frac{Q}{A}$$

per unit of time and unit of area. Since the water in the tubes leading from the holes to the gages is stationary, the reading on the gages is not affected by any clogging of the walls of the holes B_1 and B_2. If γ_w is the unit weight of the water and p_1 and p_2 the two gage readings, the percolation of the water from B_1 to B_2, through a distance l, is associated with a loss of head

$$h = \frac{p_1 - p_2}{\gamma_w}$$

According to Darcy's law $v = kh/l$, whence

$$k = v\frac{l}{h} = \frac{Q}{A}\gamma_w\frac{l}{p_1 - p_2} \quad \ldots\ldots(10)$$

Until permeability tests are carried out in this or a similar manner, experimental determination of the permeability of rocks cannot be considered reliable.

STRENGTH OF CONCRETE AND ROCK IF PORE WATER PRESSURE IS LOWER THAN THE CONFINING PRESSURE

In the concrete of a storage dam and in the rock beneath the dam, the pore water pressure u_w is likely to be considerably lower than the confining pressure p_c. In this event, it is convenient to divide the confining pressure into two parts, $\bar{p}_c = p_c - u_w$ and u_w,

$$p_c = \bar{p}_c + u_w$$

The pressure $\bar{p}_c$ will be referred to as *effective confining pressure.* Its influence on the strength of saturated material is practically identical with that of a confining pressure $p_c = \bar{p}_c$ on the strength of a specimen with empty voids. For concrete this influence is approximately determined by Eq. 2. The influence of the second part, u_w, depends on the boundary porosity as explained before. If $\bar{p}_c = 0$ or $p_c = u_w$, the boundary porosity of concrete, Solenhofen limestone, and probably that of all crystalline and clastic rocks is close to one hundred per cent. However, a confining pressure $\bar{p}_c$ in excess of u_w crowds the individual constituents of the material together and establishes intergranular contacts which do not exist if $p_c = u_w$. These contacts reduce the boundary porosity and, as a consequence, they reduce the influence of the pore water pressure on strength. Once the voids are almost entirely closed, the influence of the pore water pressure becomes negligible.

The influence of the effective confining pressure $\bar{p}_c$ on the boundary porosity can be estimated from the relation between confining pressure and cubic compressibility of uncovered and jacketed specimens. The cubic compressibility β at a given confining pressure p_c per unit of area is equal to the ratio between the specific volume decrease dv and the pressure increase dp_c which has caused the volume decrease, or

$$\beta = \frac{dv}{dp_c}$$

The cubic compressibility of uncovered specimens of a porous material consisting of elastically isotropic particles of the same substance is identical with that of the individual particles, because the size of the voids decreases in exactly the same proportion as the size of the particles. This statement also applies approximately to concrete and rock.

If a jacketed specimen of a porous material is acted upon by a confining pressure p_c, the individual particles are not only compressed but also deformed. At low pressures the volume decrease is chiefly due to a decrease of the volume of the voids. It is associated with a decrease of the boundary porosity n_b. Hence at low pressures, the cubic compressibility of the jacketed specimens should be much greater than that of the uncovered ones. However, as soon as the voids are completely closed the two values become identical, and the boundary porosity becomes equal to zero.

In Fig. 10 the lower curve represents the results of compression tests on uncovered specimens of Rockport granite. The upper curve shows the results of similar tests on jacketed specimens of the same material (Zisman (15)). The decrease of the vertical distance between the two curves from left to right is indicative of the corresponding decrease of the volume and boundary porosity. The diagram indicates that the volume and the boundary porosity of the tested granite certainly do not become equal to zero at effective confining pressures less than 300 or 400 kg. per sq. cm. Even at 700 kg. per sq. cm., the porosities may still be quite high, because the difference between the ordinates of the two curves is still very considerable.

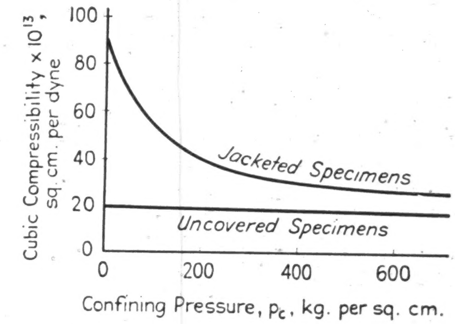

FIG. 10.—Relation Between Confining Pressure and Cubic Compressibility. (*After W. A. Zisman*)

No compressibility curves for concrete have come to the author's attention. But since the porosity of concrete is much higher than that of a sound granite, it is to be expected that the pressure required for closing the voids in concrete is higher than for granite.

In connection with engineering problems, effective confining pressures of more than 10 or 15 kg. per sq. cm. are seldom encountered. At such low pressures, the influence of the effective confining pressure on the boundary porosity can safely be disregarded. Under these circumstances, the compressive strength q_c of a material subject to both an effective and a neutral confining pressure can be determined by means of two series of triaxial compression tests, one of which must be performed on jacketed specimens and the second one on specimens without a jacket. For specimens without jacket, the confining pressure is identical with the pore water pressure or neutral pressure u_w. The increase of the compressive strength from q'_{c1} to q'_{c2} due to an increase of the neutral pressure from u_{w1} to u_{w2} can be expressed by an empirical equation

$$\frac{q'_{c2} - q'_{c1}}{u_{w2} - u_{w1}} = f_w \ldots\ldots (11)$$

wherein f_w is an empirical value representing the test result. The increase of the compressive strength of jacketed specimens from q_{d1} to q_{d2} due to an increase of the liquid pressure on the jacket from $\bar{p}_1$ to $\bar{p}_2$ can be expressed by a similar equation

$$\frac{q_{d2} - q_{d1}}{\bar{p}_2 - \bar{p}_1} = f_e \ldots\ldots (12)$$

For the present purpose, it is justifiable to assume that f_w and f_e are constants for the material under investigation. Therefore, we obtain on the basis of Eqs. 11 and 12 for the compressive strength q_c of a porous material subject to both an effective and a neutral confining pressure

$$q_c = q_u + f_w u_w + f_e(p_c - u_w). (13)$$

For Solenhofen limestone and for concrete, f_w was found to be almost zero. Hence for these materials

$$q_c = q_u + (p_c - u_w)f_e \ldots . (14)$$

Considering the results of Zisman's compressibility tests, it seems probable that this equation is approximately valid for all granular rocks subject to effective confining pressure of less than 10 or 15 kg. per sq. cm.

Equation 14 implies that the individual constituents of saturated concrete and rock under moderate effective confining pressures are almost completely surrounded by liquid. Hence the hydrostatic uplift in concrete and rock at the base of storage dams is almost as fully active as it is in a cohesionless sand. The practical implications of this condition have been discussed elsewhere (Terzaghi (**14**)).

In connection with geological problems, the strength of rocks under effective confining pressures of more than several hundred atmospheres requires consideration. At these pressures the volume compressibility β of jacketed specimens becomes almost as independent of the confining pressure as that of uncovered ones. If at that stage the values of β were the same for both types of specimens, one could assume that the voids are closed and that the porosity is almost zero. However, the values continue to be different as shown in Fig. 10. Hence the compressive strength of rocks subject to a neutral pressure combined with a high effective pressure can be determined only by means of the test arrangement illustrated by Fig. 1. Until such tests are made, the stress conditions for the failure of rocks at depth remain a matter of opinion.[7]

CONCLUSIONS

1. Concrete or rock specimens acted upon by a confining pressure supplemented by a unidimensional pressure may fail by splitting, pseudo-shear or shear.

2. Experiments have shown that the unidimensional excess pressure q_c required to break a given specimen depends both on the total confining pressure p_c and on the porewater pressure u_w. If the pore water pressure u_w is zero, q_c increases very rapidly with increasing values of p_c. On the other hand if the pore water pressure u_w is equal to the total confining pressure, $u_w = p_c$, the effect of p_c on the compressive strength q_c is imperceptible.

3. An inquiry into the physical causes of the striking influence of the porewater pressure u_w on the strength q_c of a specimen at a given confining pressure p_c leads to the conclusion that the individual constituents of saturated concrete and rock in a stress-free state are almost completely surrounded with liquid. In other words, the solid constituents of these materials are interconnected only over very small areas of their total surface. The corresponding boundary porosity is almost equal to 100 per cent. In a material with such a high boundary porosity the hydrostatic uplift is almost as active as in a cohesionless sand.

4. By comparing the results of volume compression tests on jacketed specimens

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[7] Griggs (**3**) expressed the opinion that the state of rocks at great depth may be comparable to that of jacketed specimens because, according to Lindgren (7), there is ample evidence "which indicates that rocks at depth are not saturated with water" (Griggs (**3**), p. 566). Most of the evidence presented by Lindgren refers to visible or recoverable water. The present author noticed in a coal mine, at a depth of about 2500 ft. below the surface that the concrete shaft lining was dust dry. The shafts were surrounded by a very porous sandstone saturated with water under a hydraulic head of about 2000 ft., which caused exceptional difficulties during construction. Hence the dryness of the surface of the concrete merely indicated that the surface evaporation exceeded the recharge across the concrete shell. If the shaft were drowned, the voids of the concrete would be completely filled with water under a head of 2000 ft. The permeability of crystalline rocks such as marble or granite is much lower than that of concrete. Hence if the walls of a shaft in one of these rocks appears to be dry, one can only conclude that the surface evaporation exceeds the recharge and that the fissures in the rock are practically closed. It is conceivable and it has been observed that highly porous strata located at a considerable depth below the uppermost water table contain almost no water. However, in such instances the conditions for hydraulic equilibrium require that the voids are filled with gas under a pressure equal to the depth of the saturated zone located above the empty stratum multiplied by the unit weight of the water. An exception to this rule is possible only if the water table located above the porous stratum constitutes an independent, perched water table. The pressure in the gas contained in the voids of a rock has exactly the same mechanical effect as a porewater pressure u_w.

with those of specimens without any cover it is found that the effect of confining pressures up to 15 or 20 tons per sq. ft. on the boundary porosity of concrete and rock is negligible. Since the boundary porosity of stress-free specimens is almost equal to 100 per cent, the corresponding boundary porosity of specimens under effective confining pressure of less than about 20 tons per sq. ft. is also very close to 100 per cent and the constituents of the confined specimens are also almost completely surrounded with liquid. Therefore, the common conception that the hydrostatic uplift acts only on one half or two thirds of the base of concrete storage dams appears to be erroneous. This conclusion could be verified by means of the test arrangement illustrated by Fig. 1. However, the results of such an investigation can be predicted fairly closely on the basis of the existing experimental data which have been analyzed in this paper.

5. The compressive strength q_c of saturated concrete acted upon by a confining pressure p_c is roughly equal to

$$q_c = q_u + 4.1\ (p_c - u_w)$$

wherein q_u is the standard strength and u_w the pore water pressure. The equation is certainly valid for values of $p_c - u_w$ of less than about 20 tons per sq. ft. and it is probably approximately valid for much higher values.

6. The effect of the porewater pressure on the strength of rocks located between a depth of about 100 ft. and 20,000 ft. could be determined only by means of the test arrangement illustrated by Fig. 1. Within a depth of about 100 ft., the hydrostatic uplift is almost fully active; at a depth of more than 20,000 ft. it may be negligible, but is not necessarily so.

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DISCUSSION

Mr. Douglas McHenry[1] (*by letter*).—In 1942 Serge Leliavsky[2] reported the results of tests in which he measured the effect of pore pressure on the tensile and compressive strength of hollow cylinders of concrete. He found that the boundary porosity, n_b, ranged from 0.85 to 0.98, averaging 0.92, thus providing some confirmation of Mr. Terzaghi's analysis. Although Leliavsky's tests appear to be among the best which have been reported, several points in connection with the technique and the interpretation must be questioned. For example, the distribution of pore pressure was not uniform at the time of failure, and one questions whether failure was not influenced more by the maximum than by the average pressure. Also, the fluid pressure acted over a portion of the cylindrical surfaces of the specimens as well as in the pores, and Bridgman[3] has shown that external pressure applied in this way may result in a rather pronounced reduction in axial tensile strength. The experimental determination of n_b is a problem which is beset with many possibilities of error, but it is doubtless highly significant that much of the experimental data indicate that n_b may be in the neighborhood of 0.8 or higher, possibly approaching rather close to unity.

This matter is of considerable importance to the designers of hydraulic structures, and on that account the Bureau of Reclamation has under way a program of triaxial strength tests similar to the one suggested by the author. The tests have not yet progressed to a stage which warrants publication of the results; but it is expected that they will furnish some of the experimental data needed in connection with the author's theoretical treatment. The triaxial testing equipment has been described elsewhere,[4] and it need only be mentioned here that the testing machine accommodates specimens up to 6 by 12 in. in size, and that the axial and circumferential pressures may be as high as 125,000 psi.

The author has discussed two mechanisms by which immersion may reduce the compressive strength of rocks: part of the intercrystalline matrix may be dissolved, or else immersion may eliminate the strengthening effect of surface tension of the interstitial liquid. He also refers to the fact that the immersion of dry rock specimens reduces their compressive strength "in exceptional cases even by 20 per cent," and cites this as evidence that the boundary porosity is close to unity. The Bureau of Reclamation laboratories recently tested twenty 2 by 4-in. drill core specimens of a quartz-mica schist which showed an even more extreme behavior. The average compressive strength of ten oven-dry specimens was 13,590 psi., while that of ten wet specimens (immersed for 15 days at room temperature) was 6430 psi., showing a reduction of 53 per cent. Modulus of elasticity was measured for both the wet and dry conditions on each of the twenty specimens and averaged 2,210,000 psi. for the dry rock against 1,310,000 psi. for the wet rock, or a reduction of 41 per cent. The average absorption of water by weight was only 0.32 per cent. The author has not discussed the effect of immersion nor of pore pressure on modulus of elasticity, and the literature contains very few test data on this subject. It would be interesting to know what conclusions Mr. Terzaghi would draw from the observation of a roughly parallel reduction in strength and elastic modulus as a result of immersion.

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[1] Bureau of Reclamation, Denver, Colo.

[2] Serge Leliavsky, "Uplift in Dams," *Nature*, Vol. 149, pp. 137–138, (1942).

[3] P. W. Bridgman, "Considerations on Rupture Under Triaxial Stress," *Mechanical Engineering*, Am. Soc. Mechanical Engrs., Vol. 61, pp. 107–111 (1939).

[4] R. F. Blanks and D. McHenry, "Large Triaxial Testing Machine Built by Bureau of Reclamation," *Engineering News-Record*, Vol. 135, pp. 171–173, (1945).

MESSRS. S. P. WING[5] AND ARTHUR RUETTGERS[5] (*by letter*).—The interest in Mr. Terzaghi's paper is rather in its stimulating hypotheses than in the experimental data which, in large measure, he draws from somewhat inaccessible foreign sources. The discussion which follows bears on that part of the paper dealing with the mechanics of making permeability tests and with the interpretations of results of such tests.

Mr. Terzaghi states that "reliable data regarding the permeability of rocks and other pseudo-isotropic materials are still very scarce." As an example of unreliable data yielding permeability coefficients which he suggests are much too low, he makes reference to tests of plate-shaped specimens of rock only $\frac{1}{2}$ in. thick obtained by sawing or cutting.

It is believed past experience supports the position: (1) that there is a skin effect from pore clogging in specimens so obtained, (2) that this skin or end effect, unless evaluated and allowed for, could lead to large errors in reported test results, particularly for thin (short) specimens, and (3) that errors due to end effect might be avoided, at least in tests of small-diameter drill cores of fine textured rock, by employing much thicker (longer) specimens and a test apparatus of the type illustrated by the author's Fig. 9.

If Mr. Terzaghi is of the impression that permeability apparatus equipped to measure internal pressures is new, he will be interested to know that it was used, with apparent satisfaction, some 15 years ago in making tests of 1$\frac{15}{16}$ by 12-in. sandstone drill cores from the foundation area of Madden Dam. A striking feature of these tests was the sharp pressure drop in both ends of the sawed specimens.

The end effect is probably more pronounced in cast concrete specimens than in rock specimens, because in addition to pore clogging incident to surface treatment there is the gradation in physical structure of the concrete from the interior to the surface. Moreover, tests of concrete are often of long duration, so that rust and other water-borne substances add to the difficulty of preventing surface sealing.

In the extensive concrete permeability investigations for Boulder Dam, the results of which were published in 1935[6], the apparatus used was similar to that shown in the author's Fig. 9 except that there was no provision for measuring internal pressures. However, the cylinder end effect was evaluated and utilized in reducing the experimental data for test specimens of various lengths to a common basis. Although the corrected permeability coefficients were reported in terms of a 12-in. length of specimen with end effects, they may be readily converted to apply to an equal length of interior concrete by merely increasing the values 50 per cent, inasmuch as a 12-in. length with end effects was found to be equivalent, on the average, to an 18-in. length without end effects. The data derived from the Boulder Dam experiments and used in making adjustment for the effect of specimen end condition and of other factors such as length of cure served another useful purpose in that they enabled a rough comparison of the results of the Bureau of Reclamation tests with those from four independent sources. The fact that this comparison showed reasonable agreement indicates that the author may not be fully aware of the quantity of reliable or usable permeability data already available, at least with respect to concrete.

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[5] Bureau of Reclamation, Denver, Colo.

[6] A. Ruettgers, E. N. Vidal and S. P. Wing, "An Investigation of the Permeability of Mass Concrete with Particular Reference to Boulder Dam," *Proceedings*, Am. Concrete Inst., Vol. 31, p. 382 (1935).

There is admittedly still room for improvement in permeability apparatus, specimen preparation, and testing technique. However, progress in these directions is likely to be slow for the reason that the successful conduct of a water permeability test, particularly of concrete, is dependent on the meticulous performance of a host of detail operations, and one ill-considered change may entail the loss of considerable labor and time, if not the entire test series or program. Furthermore, innovations have a habit of introducing problems of their own.

The current procedure of the Bureau of Reclamation differs in relatively few respects from that reported in the literature in 1936.[7] The end effects and tendency for pore obstruction are believed to have been virtually eliminated by using a freshly broken section of interior concrete (Fig. 1) for the top surface of the cylinder as tested, by covering this top surface with a 4 to 6-in. filter layer of Ottawa sand composed of 70 per cent No. 50 to No. 30 and 30 per cent No. 100 to No. 50 particles, and by substituting compressed air for oxygen as the medium for applying pressure to the water. The number of seal leaks has been reduced by substituting stearin pitch, a byproduct of soap manufacture, for the sealing material, and by seating the test specimen in plaster of Paris before pouring the pitch around the side. To obtain the concrete surface illustrated by the accompanying Fig. 1, a thin collar is inserted in the concrete cylinder mold to form a plane of weakness and the cylinder is broken in two just prior to placing the test specimen in the permeability container. By using two collars a freshly broken surface may be provided

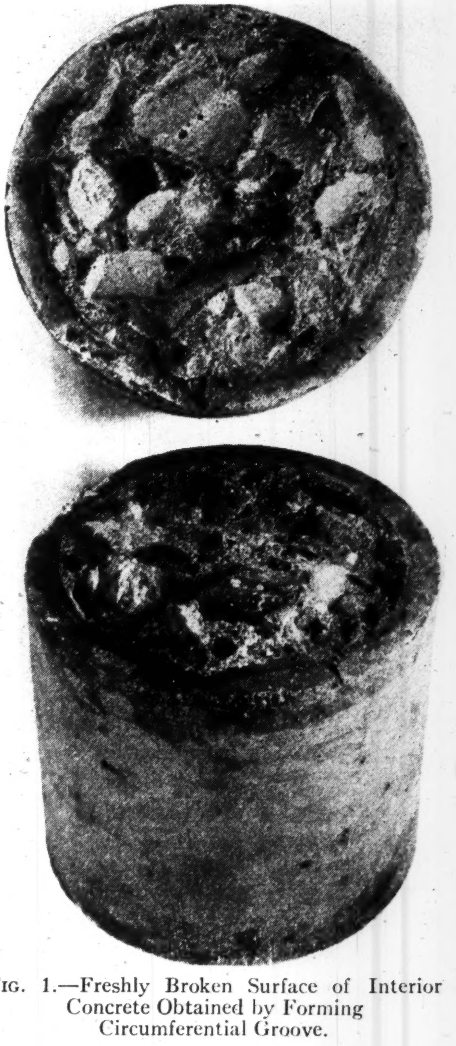

FIG. 1.—Freshly Broken Surface of Interior Concrete Obtained by Forming Circumferential Groove.

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[7] E. N. Vidal and G. A. Samson, "Apparatus and Technique for the Bureau of Reclamation Concrete Permeability Tests," *Proceedings*, Am. Soc. Testing Mats., Vol. 36, Part I, p. 289 (1936).

at both ends of the test specimen, as the rim produced by the collar affords a plane surface for seating. Similar results might be obtained with rock cores of adequate dimensions by breaking out sections, after cutting circumferential grooves at planes of desired break, rather than by sawing.

With a satisfactory solution to the problem of end effect, the writers see no particular advantage in resorting to internal pressure measurements in tests aimed primarily at determining the coefficient of permeability, except as a means of securing supplemental information for special purposes. On the contrary, the writers envisage a potential disadvantage from the inclusion of such measurements, aside from the extra operations and possible mechanical difficulties introduced by the added facilities. The disadvantage lies in the uncertainty that point measurements will be representative of over-all conditions in the test specimen. Concrete, and to some extent rock, is homogeneous only in a statistical sense if the area or volume considered is large enough to contain many individuals of the largest aggregates or rock crystals. With respect to percolation, general observation of concrete specimens during and after test leads one to suspect that internal flow conditions may be highly erratic. For example, at the bottom of a 6-in. diameter cylinder showing outflow it is not uncommon to find dry spots along with wet spots or with the outflow concentrated at the boundaries of the larger aggregates. It seems reasonable to expect, therefore, that a pressure reading at a single point in a horizontal section might show wide divergence from a true section average, depending on the permeability characteristics of the small region where the entrance to the proposed pressure tube happens to be located.

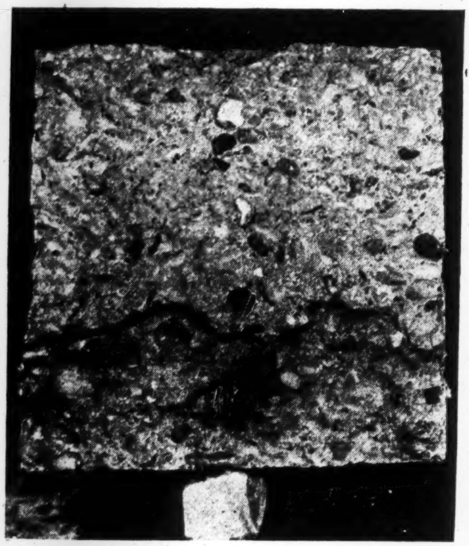
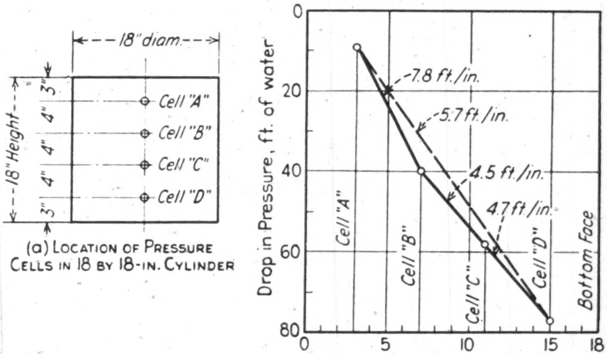


FIG. 2.—Split Concrete Permeability Specimen After Test, Showing Line of Maximum Water Penetration and Degrees of Saturation. (Pressure face at bottom.)

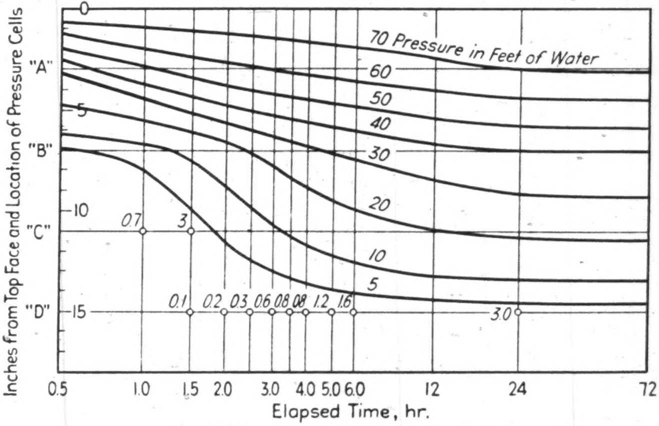
A number of years ago a few experiments were run by the Bureau of Reclamation on 18 by 18-in. concrete cylinders in which hydrostatic pressure indicators of the diaphragm type were embedded with a view to investigating the intensity and distribution of water pressures to be anticipated near the upstream face of Shasta Dam. The results of these tests were largely negative in so far as measurement of water pressures is concerned because it was found impracticable to permeate the specimens without using pressures exceeding the capacity of the upper pressure cells. Nevertheless, some pertinent data were obtained on variation in water movement and on pressure readings obtained with the substitution of compressed air for water.

The accompanying Fig. 2 shows the variation both in water front and degree of saturation in the interior of one of the specimens. The photograph was taken with the cylinder upside down and with the line of maximum water penetration emphasized with crayon. It was stated in the test report that the concrete was "saturated" in the region immediately surrounding the first pressure cell (along vertical center line and 3 in. from bottom in photo) and "very dry" around the second cell (7 in. from bottom and close to water line in photo.)



(a) LOCATION OF PRESSURE CELLS IN 18 BY 18-IN. CYLINDER

(c) PRESSURE DROP AFTER 24 TO 72 HR.



(b) VARIATION IN PRESSURE WITH TIME

FIG. 3.—Permeability Tests—Air Pressure Distribution.

The results of an air percolation test on a similar specimen are indicated in the accompanying Fig. 3. Figure 3(*a*) shows the location of the pressure cells, Fig. 3(*b*) the indicated pressure distribution at various periods of elapsed time, and Fig. 3(*c*) the indicated pressure gradients after the pressures had become stable. Assuming the measured air pressures to be reliable, the data at first glance indicate a reasonably uniform pressure distribution along the cylinder axis. Analysis, however, reveals the presence of appreciable variation. Considering first only the pressure gradients between successive pressure cells, Fig. 3(*c*) shows that the values at 24 to 72 hr. vary from 4.5 ft. per in. to 7.8 ft. per in., the corresponding coefficient of variation being about 25 per cent. Computed permeability coefficients would show the same variation, since they are inversely proportional to the pressure gradients. If the pressure gradients between the ends of the cylinder and their adjacent pressure cells are also taken into account, the coefficient of variation is increased to about 50 per cent. Measured data on pressure variations in horizontal planes are not available, but if they are assumed to be of the same magnitude as the over-all variations in pressure gradients in the vertical direction, the showing is none too favorable for the author's suggested form of permeability apparatus.

The surprising feature of the data in Fig. 3 is that in spite of the fact that the end faces of the test cylinder were merely chipped, there is no evidence of the usual end effect. In fact, an opposite effect is indicated, namely, that the concrete at the faces was more permeable than that of the interior.

MR. D. W. KESSLER[8] (*by letter*).—Professor Terzaghi should be commended for his daring excursion into the theory of stresses in materials under compression, and it is interesting to see what our experimental data lead to. At least one of his conclusions is so startling that it behooves us to examine our methods carefully, and particularly the assumptions involved, to see what we are actually determining when we make a compression test.

One necessary assumption made in connection with the compression test is that the load is applied uniformly over the pressure faces. Another is that the load is applied parallel to the axis of the specimen throughout the test. These ideal conditions cannot be obtained in actual tests for two reasons: (1) it is impossible to make plane faces on test specimens, and (2) testing machines are not perfect. It is a tedious operation for a skilled artisan to grind a surface on even a small specimen so that no part of the area departs from a plane by more than 1 mil. It seems likely that many experimenters assume that the surfaces are accurate enough without attempting to measure them, when in reality they may depart from planes by several mils. How seriously these irregularities may affect the uniformity of loading obviously depends upon the size of the specimens and the modulus of elasticity of the material. Porcelain has a modulus of elasticity as high as 40×10^6 psi., and the dimensions of compression specimens are usually not greater than 1 by 1 by 2 in. High spots on the specimens could easily result in high load concentrations sufficient to cause splitting failures such as reported for this material. Contrary to the statement that porcelain always fails by splitting, men at the National Bureau of Standards who have made numerous tests on this material, tell me they do not obtain splitting failures. This discrepancy in data may be due to the fact that great care is taken here in grinding the bearing faces of specimens. It hardly seems logical to ascribe splitting failures in porcelain to "intergranular wedging action," because the material is so fine grained that a microscope is necessary to show that it is granular. In about five thousand compression tests made on various types of stone, I cannot recall ever seeing a splitting failure. If one were obtained, I would insist on repeating the test, because a splitting failure does not give the compressive strength of a material. Stones of high compressive strength usually shattter into so many small pieces that it is difficult to identify any of them as cones or pyramids. This type of failure is also obtained on porcelain.

About twenty-five years ago I made some elasticity and flow tests on the rock through which one of the cuts was made for the Panama Canal, in connection with a study to determine the cause of slides. In the course of this work some evidence was found that the testing machine was not giving a uniform distribution of load on the specimens. The machine was dismantled to find the cause of the poor performance. Below the bed casting four thick rubber washers were found, one on each screw between the base of the machine and the gears producing the loads. As the loads were applied, each rubber washer was compressed in proportion to its resistance to deformation. Since the washers were in various stages of disintegration due to oil reaching them, they allowed the loading head to tilt continuously as loads were applied, and hence the machine was acting more like the jaws of a stone crusher than as a testing machine should act. When the manufacturer of the machine was advised of this, he argued that the rubber washers were an outstanding feature of his machine.

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[8] Chief, Stone Section, National Bureau of Standards, Washington, D. C.

This experience aroused some skepticism as to the performance of testing machines in general, and it was decided to look into the matter further. A material which appeared to be uniform was worked up into compression test specimens which were finished with much more than the usual care. Four sets of these were tested here on different testing machines, and five sets were sent to five of the best known testing laboratories for comparative results. One of these laboratories did not take advantage of the offer, but the other four made tests. This gave comparisons on eight testing machines, and the results were so variable that a summary is given as follows:

Average of 32 tests on 8 machines	18,800 psi.
Highest average for 1 machine	25,600 psi.
Lowest average for 1 machine	11,900 psi.
Highest individual result	26,800 psi.
Lowest individual result	10,300 psi.

All of these machines had been calibrated in the usual way, but such calibration checks only the weighing system and does not determine such features as may affect the uniformity of loading in a compression test. Great improvements have been made in testing machines in the past twenty years, and it should not be inferred that the modern ones are apt to give such erratic results, but it should be noted that the results upon which Mr. Terzaghi has based his studies were made at various institutions, and many of the data were obtained several years ago.

One type of stress which occurs in a compression test seems to have been disregarded in his analysis, namely, that induced by constraint at the ends due to friction on the bearing plates. It is difficult to predict whether these stresses would be significantly large under a confining pressure test, because the confining liquid would probably act as a lubricant thereby minimizing the frictional forces.

The conclusion that the boundary porosity in concrete is nearly 100 per cent leads one to wonder how this material could have any appreciable tensile strength in a saturated condition. Tests made here on common mixtures of concrete cured in damp storage and tested without drying have given tensile strengths from 300 to 600 psi. Many of the fractures passed through quartz pebbles.

In order to make proper deductions from the results of compression tests under two or more conditions, it seems desirable that the tests should all be confined to one material which is much above the average in homogeneity. The tests should all be made on one testing machine and preferably checked on one or more others. Particular care should be taken to prepare all of the specimens with bearing faces as near to plane surfaces as possible.

MR. K. TERZAGHI (*author's closure, by letter*).—Mr. McHenry has observed that immersion reduced both the compressive strength and the modulus of elasticity of a hard quartz-mica schist by roughly fifty per cent. This interdependence between the two quantities is an analogue to the fact that both the modulus of elasticity and the confined compressive strength of every cohesionless accumulation of mineral particles such as sand increase approximately in simple proportion to the confining pressure. Furthermore, if the compressive strength of a specimen of plastic clay increases on account of desiccation by 100 or 200 per cent the modulus of elasticity also increases by about the same amount. Since desiccation increases the modulus of elasticity of the quartz-mica schist, it would be interesting to find out whether a confining pressure acting on a dry specimen has similar effects.

Messrs. Wing and Ruettgers raise various objections against the method which the author proposed for determining the coefficient of permeability of rocks. The method proposed by the author is a common-place one in soil testing, but the author was not aware that it has also been used in connection with rocks. The shortcomings of the method are quite obvious. Therefore, the author was pleased to learn from the discussions that very much better methods are already available. He hopes that they may be used before long to get some information on the permeability of the most common crystalline rocks.

Mr. Kessler doubts the existence of the splitting failure. This type of failure was described in detail and discussed in the various publications of the Eidgenössische Materialprüfungsanstalt in Zürich. It constitutes one of a great variety of failures of quasi-isotropic materials which have been observed. At present the concepts which have been worked out by the Swiss investigators regarding the processes which lead to the failure of quasi-isotropic materials are the only comprehensive and rational ones we have. Considering the influence of the method of testing on the type of failure, alternative concepts based on the results of tests made in American laboratories would be very desirable, but so far none has been presented.

Regarding the failure of porcelain, the author refers Mr. Kessler to the photographs in reference 10. The types of failure described by Mr. Kessler differ no less radically from the ideal shear failure than the splitting failure described by the Swiss investigators. Therefore, they must be considered as pseudo-shear failures. For the time being the wedging hypothesis is the only rational explanation of the pseudo-shear failures which has been proposed. The author cannot agree with Mr. Kessler's objections against this hypothesis, because the size of the grains is irrelevant. It changes the linear scale, but not the pattern of the internal forces which lead to failure.

Mr. Kessler further refers to striking discrepancies between the values of the compressive strength of specimens of identical materials obtained by means of different testing machines. Such discrepancies are of great interest from the point of view of testing technique but they have no bearing on the conclusions presented by the author since none of them was based on a comparison between test results obtained with different testing machines.

In the last part of his discussion Mr. Kessler raises the question whether the high tensile strength of a material is compatible with a very high boundary porosity. This question has often been asked before. The answer seems to be that the resistance against the tension failure of minute connecting links between grains is determined not by the empirical but by the real strength of the material. On account of the stress concentration at the walls of micropores and haircracks the empirical strength of large specimens does not exceed a small fraction of the real strength of the tested material. This has been known to physicists for many decades. Hence to explain the great strength of the bond between grains it is sufficient to assume that these bonds are flawless.

EFFECT OF TYPE OF TEST SPECIMEN ON APPARENT COMPRESSIVE STRENGTH OF CONCRETE

By Bryant Mather[1]

Synopsis

Two programs of strength testing are reported, in each of which concrete from the same sample or batch was tested using either drilled cores or molded cylinders for comparison with modified cubes. A total of 2375 strength tests were made and from the resulting data it is suggested that the choice of type of specimen may considerably affect the compressive strength value obtained for the concrete.

The compressive strength of concrete is, in standard practice,[2] calculated in pounds per square inch from the average cross-sectional area of a nominal 6 by 12-in. cylinder and the total load indicated by the testing machine at the time of failure. Procedures by which this standard cylindrical specimen should be, molded, consolidated, stored, prepared, and loaded are specified in detail.[2, 3] It has been shown that the compressive strength value will be considerably affected if any of several of the details of the specified procedure are varied. Notwithstanding the relative sensitiveness of the standard procedure, two other methods, using different types of test specimens, have been accepted as standard by the Society for use in the determination of the compressive strength of concrete. In one case[4] the specimen contemplated is a cylindrical, drilled core of unspecified length and of a diameter at least three times the nominal maximum size of the coarse aggregate used in the concrete. In the other case[5] portions of beams broken in flexure (modified cubes) are proposed as test specimens.

Two programs of compression testing are discussed below; in the first a comparison is made between cylindrical drilled core specimens and portions of sawed beams broken in flexure; in the second a comparison is made between molded 6 by 12-in. cylinders and molded beam sections of various lengths tested as modified cubes.

Program 1—Pavement Concrete

Between September, 1943, and March, 1945, 258 slabs of pavement made with portland cement were removed from 27 military airfields in the northeastern states and shipped to this laboratory for test. Compression tests were made on both drilled cores and modified cubes

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[1] Engineer, Central Concrete Laboratory, Corps of Engineers, U. S. Army, Mount Vernon, N. Y.

[2] A.S.T.M Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (C 39-44), 1944 Book of A.S.T.M. Standards, Part II, p. 470.

[3] A.S.T.M. Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (C 31-44) *Ibid.*, p. 466 and A.S.T.M. Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192-44 T) *Ibid.*, p. 1344.

[4] A.S.T.M. Standard Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (C 42-44), *Ibid.*, p. 460.

[5] A.S.T.M. Standard Method of Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (C 116-44), *Ibid.*, p. 472.

TABLE I.—FIELD CONCRETE—PAVEMENT SLABS.

Average Compressive Strengths, psi., Corrected to h/d or $h/w = 2$.

Location		Modified Cubes	Cores
BO-30	No. 1	4495	6470
	No. 2	5140	7895
	No. 1	6020	7375
	No. 2	5175	6305
	No. 3	5560	6935
	No. 4	4980	5210
	No. 5	5170	5270
	No. 6	5325	6285
PH-11	No. 1	5075	4365
	No. 2	5205	5215
	No. 3	5020	5435
	No. 4	5095	4965
	No. 5	5365	4470
	No. 6	4975	5465
	No. 7	4720	5350
	No. 17	4870	4625
BAB	No. 6	5985	5035
	No. 7	4990	5300
	No. 8	4910	4475
	No. 9	4160	4080
	No. 10	4220	4485
	No. 11	4560	4800
BO-31	No. 1	1260	1025
	No. 3	1515	870
	No. 5	945	1375
	No. 6	1615	1715
	No. 7	1650	1645
	No. 8	1200	1185
PH-12, 17	No. 1	4750	4535
	No. 2	4915	5030
	No. 3	4440	4620
	No. 4	5635	4850
	No. 5	4155	4225
	No. 6	3155	3010
	No. 7	4665	5010
NY-324	No. 1	6070	6705
	No. 2	5215	5765
	No. 3	6555	6255
	No. 4	6435	6375
	No. 5	6560	6875
	No. 6	5530	7515
	No. 7	5870	6465
BO-16	No. 1	5505	6180
	No. 2	4860	6205
	No. 3	4410	5365
	No. 4	3340	4110
	No. 5	3285	3180
	No. 6	1365	1570
	No. 7	3080	2730
	No. 8	5070	6160
LG	No. 1	5020	5855
	No. 2	4655	5805
	No. 3	5655	6840
MS	No. 1	5130	6165
	No. 2	5805	6375
	No. 3	5995	6280
BMA	No. 1	5425	4345
	No. 4	5535	5445
	No. 5	5955	7770
PH-14	No. 1	5955	6175
	No. 2	5035	6390
	No. 3	5995	5140
	No. 4	4690	5795
	No. 5	5215	5295
MF	No. 1	2765	3425
	No. 2	5360	5175
	No. 3	4480	4895
	No. 4	5600	4680
	No. 5	4965	4855
	No. 6	4765	5655
	No. 7	4765	5430
	No. 8	4785	5095
	No. 9	4895	5850
	No. 11	5200	4895
	No. 12	5155	6525
	No. 13	5345	6215
	No. 14	5640	6905
	No. 15	5385	6855
	No. 16	3845	3150
MF (*Cont'd*)	No. 17	3950	5700
	No. 18	6320	6715
	No. 19	5490	6715
	No. 20	2905	2550
	No. 21	4760	4175
	No. 22	5890	6750
	No. 23	5635	6885
	No. 26	4605	4315
	No. 28	3945	3810
NY-325	No. 1	6575	5325
	No. 2	6300	5320
	No. 3	4600	5535
	No. 4	5900	6900
	No. 5	4250	4915
	No. 6	5645	5900
	No. 7	6270	4850
NCA	No. 18	4950	5235
	No. 19	4940	4960
NY-193	No. 1	5300	6825
	No. 2	4960	6045
	No. 3	4810	6085
	No. 4	5110	6380
PCA	No. 1	4990	6445
PIA	No. 7	4580	5320
	No. 9	4575	4540
	No. 10	5030	4850
	No. 11	3925	4105
	No. 12	4875	5245
	No. 182	5400	6120
	No. 183	5420	5680
ADB	No. 1	5105	5715
	No. 2	5160	4940
	No. 3	5945	6325
NY-190	No. 1	5030	6205
	No. 2	5210	5520
	No. 3	4295	4890
	No. 4	4835	4050
	No. 5	3740	3415
	No. 6	5205	5395
	No. 7	4010	4160
	No. 8	4015	4045
	No. 9	4630	6155
	No. A-1	4785	5310
	No. A-2	4505	5695
NY-73	No. 1	4695	5350
	No. 3	4870	5995
	No. 4	5460	6005
	No. 5	5330	4615
	No. 6	3595	3875
NY-149	No. 1	5435	6320
	No. 3	4825	4805
	No. 5	4920	4615
	No. 6	5050	4635
	No. 7	4925	5675
	No. 8	5215	4810
	No. 9	4350	4970
	No. 11	4325	5660
	No. 14	4340	4340
NY-79	No. 1	5620	6350
	No. 2	4950	5545
	No. 3	4270	5820
	No. 4	5730	4715
	No. 5	6530	5295
	No. 6	5630	5755
	No. 7	5410	5580
	No. 8	5430	5830
	No. 9	5895	5855
	No. 10	5145	5850
SAB	No. 1	5580	7165
	No. 2	5380	6840
	No. 3	4365	5280
	No. 4	4700	5685
CAB	No. 1	4965	5515
	No. 2	5265	5355
	No. 3	6190	6045
	No. 4	5855	5680
	No. 5	5615	5885
	No. 6	6180	6065

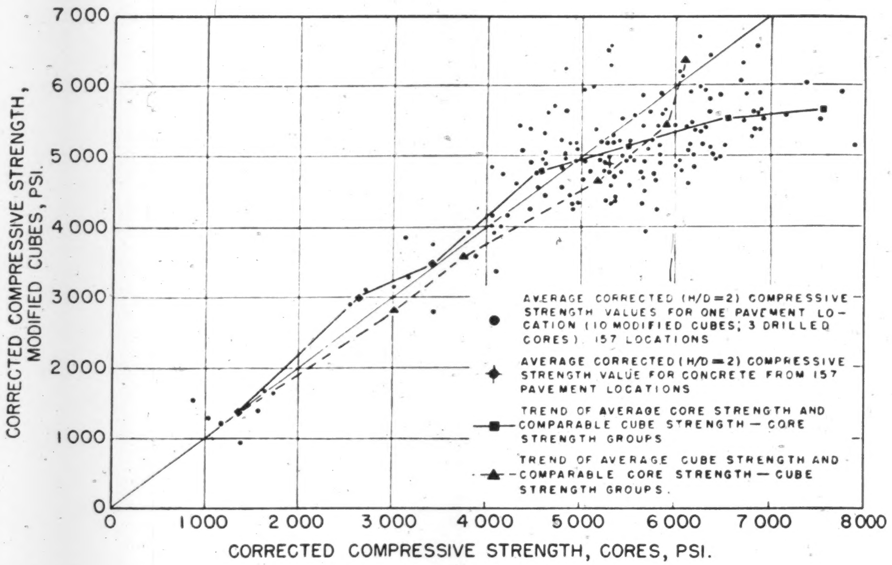

FIG. 1.—Relationship of Average Compressive Strength Values for Core and Modified Cube Specimens Cut from Slabs Removed from Concrete Pavements at Certain Army Airfields.

TABLE II.—FIELD CONCRETE—PAVEMENT SLABS.

Average Compressive Strengths of Cores and Comparable Modified Cubes from the Same Pavement Location by Core-Strength Ranges.

Core Strength Range, psi.	Number of Locations	Average Core Strength, psi.	Average Cube Strength, psi.
1000 to 1995	7	1340	1365
2000 to 2995	2	2640	2990
3000 to 3995	7	3410	3475
4000 to 4995	39	4580	4785
5000 to 5995	55	5500	5100
6000 to 6995	42	6430	5530
7000 to 7995	5	7545	5645
Total and Average	157	5270	4890

Average Compressive Strengths of Modified Cubes and Comparable Cores from the Same Pavement Location by Cube-Strength Ranges

Cube Strength Range, psi.	Number of Locations	Average Cube Strength, psi.	Average Core Strength, psi.
1000 to 1995	7	1365	1340
2000 to 2995	2	2835	2985
3000 to 3995	10	3585	3710
4000 to 4995	57	4660	5175
5000 to 5995	69	5435	5895
6000 to 6995	12	6330	6100
Total and Average	157	4890	5270

representing material from 157 pavement locations. With few exceptions, each location was represented by three cores, 6 in. in diameter and on the average approximately 6 in. in height, and ten portions of beams, 6 in. square in cross-section. A total of 472 cores and 1519 modified cubes were tested. All specimens were tested damp and all were provided with plane parallel caps of a sulfur-silica compound. All values for compressive strength were corrected to a length-diameter or height-width ratio of two by the use of the factors given in Section 7 of A.S.T.M. Method C 42.

The average compressive strength values for each type of specimen for each pavement location are given in Table I and plotted in Fig. 1. The average strengths of cores and comparable cubes by core-strength groups, and the average strengths of cubes and comparable cores by cube-strength groups are given in Table II and plotted in Fig. 1.

PROGRAM 2—LABORATORY CONCRETE

In connection with an investigation of five portland cements with and without interground additions, 42 batches of concrete were made from which two types of compression test specimens were molded. From each batch, at least five 6 by 12-in. cylinders and four modified cubes, 6 in. square in cross-section, were made. The four modified cubes consisted of one of each of the following lengths: 6¼, 8, 10, and 12 in. A total of 214 cylinders and 170 cubes were made and tested. All specimens were cured in fog to 28-days age, provided with plane parallel caps of a sulfur-silica compound, and tested damp. The materials used are listed and the data from tests of these 42 batches are given in Table III. The compressive strength values for each type of specimen for each batch are given in Table IV and plotted in Fig. 2. The average strengths of cylinders and comparable cubes of each length by cylinder-strength groups, and the average strengths of cubes of each length and comparable

TABLE III.—LABORATORY CONCRETE—MATERIALS, PROPORTIONS, AND TEST DATA ON PLASTIC MIXTURES.

Aggregate: Natural Siliceous Sand and Natural Siliceous Gravel, Long Island, N. Y.

Batch	Cement	Admixture and Amount	Actual Cement Factor, bags per cu.yd.	Water-Cement Ratio, gal. per bag	Slump, in.	Unit Weight, lb. per cu. ft.	Air Content, per cent	Sand, per cent of total aggregate
No. 1	A	Plain	5.37	6.17	2½	148.8	1.1	38
No. 2			5.39	6.17	3	149.2	0.8	38
No. 3			5.41	5.96	2	149.1	0.9	38
No. 4		NVR 0.01%	5.41	5.60	1¾	150.3	0.8	33
No. 5			5.42	5.60	¾	150.7	0.5	33
No. 6			5.41	5.80	1¾	149.1	1.5	33
No. 7		VR 0.03%	5.27	5.37	1¾	145.5	4.0	33
No. 8			5.21	5.37	2½	143.8	5.1	33
No. 9	B	Plain	5.38	6.24	2¼	149.4	0.7	38
No. 10			5.38	6.24	2¼	149.2	0.8	38
No. 11		NVR 0.01%	5.26	5.67	2¼	146.1	3.5	33
No. 12			5.26	5.67	2¼	146.1	3.5	33
No. 13			5.23	5.67	2¼	145.4	4.0	33
No. 14			5.22	5.67	2¼	145.4	4.2	33
No. 15			5.23	5.67	2	145.4	4.0	33
No. 16			5.24	5.72	3	145.0	4.1	33
No. 17		VR 0.03%	5.17	5.59	2¾	143.7	5.3	33
No. 18			5.20	5.59	2¼	144.9	4.5	33
No. 19			5.14	5.58	3	142.5	6.0	33
No. 20	C	Plain	5.36	6.00	2¼	148.1	1.6	38
No. 21			5.42	6.00	2	149.5	0.6	38
No. 22			5.40	6.00	2	149.0	0.9	38
No. 23		NVR 0.01%	5.24	5.42	2¼	145.3	4.2	33
No. 24			5.25	5.42	2¼	145.5	4.0	33
No. 25			5.17	5.42	2¾	143.1	5.6	33
No. 26		VR 0.03%	5.01	5.35	2¼	138.8	8.7	33
No. 27			5.06	5.35	2½	140.3	7.7	33
No. 28			5.05	5.35	2¼	140.2	7.8	33
No. 29	D	Plain	5.38	6.20	2¼	147.8	1.3	38
No. 30			5.40	6.20	2½	148.4	0.9	38
No. 31			5.41	6.20	2	148.7	0.7	38
No. 32		NVR 0.01%	5.06	5.66	5	139.3	7.9	33
No. 33			5.14	5.53	2¾	141.4	6.5	33
No. 34			5.14	5.53	4	141.1	6.7	33
No. 35			5.11	5.50	3	140.3	7.2	33
No. 36			5.13	5.44	3	140.7	7.0	33
No. 37	E	Plain	5.41	6.25	2¼	148.9	0.6	38
No. 38			5.41	6.25	2¾	149.0	0.6	38
No. 39			5.40	6.25	2¼	148.8	0.7	38
No. 40		NVR 0.01%	5.25	5.63	2	145.6	3.8	33
No. 41			5.21	5.63	2	144.3	4.6	33
No. 42			5.17	5.63	2½	143.1	5.4	33

TABLE IV.—LABORATORY CONCRETE.

Compressive Strengths, psi., corrected to *h*/*d* or *h*/*w* = 2.

Batch No.	Average of five 6 by 12-in. Cylinders	Modified Cubes Height as Tested = 6¾ in.			
		6¼ in. long	8 in long	10 in. long	12 in. long
No. 1	4695	3310	3710	4390	4065
No. 2	4595	3715	3635	4085	4025
No. 3	4970	4075	4545	4985	4525
No. 4	4295	3515	4125	3910	3825
No. 5	4880	4200	4710	4550	3825
No. 6	4060	3000	4250	3890	4310
No. 7	4510	3475	3625	3760	3340
No. 8	4400	3805	3135	3235	3625
No. 9	4170	3775	4035	3750	4035
No. 10	4240	3750	3600	4000	3900
No. 11	3860	3390	3185	3000	3410
No. 12	4390	3760	3850	4080	3810
No. 13	4555	3770	4030	4345	4085
No. 14	4490	4150	3925	4260	3585
No. 15	4505	3340[b]	3535	3635	3805[b]
No. 16	4315	3325	3575	3625	4025
No. 17	3960	3275	3300	3585	3340
No. 18	4240	3500	3575	3800	3550
No. 19	3730	3525	3565	3675	3215
No. 20	4975	4565	4245	4375	4350
No. 21	5250	3890	4515	3950	4800
No. 22	5390	3925	4805	5220	4810
No. 23	5120	4415	4305	3975	4335
No. 24	5180	3650	4175	3585	3715
No. 25	4535	3665	4175	4170	4060
No. 26	3750	2885	2970	2870	3025
No. 27	3670	2875	3215	2590	2825
No. 28	3715	3345	2970	2940	2990
No. 29	4345[a]	4565	4165	4575	4495
No. 30	4590	4290	3875	3715	4300
No. 31	4340	4525	3940	4240	3630
No. 32	3465	3135	3000	3085	3155
No. 33	3935	2900	3300	3265	3325
No. 34	3555	2715	2675	2285	2615
No. 35	3365	2785	2970	2970	2900
No. 36	3625	3075	3165	3250	3085
No. 37	5120	4225	4425	4460	4565
No. 38	5490	4450	5000	5250	4485
No. 39	4870	4120	4075	4445	4850
No. 40	4625	3700	3565	3855	4285
No. 41	4710	3390	4050	3925	3760
No. 42	4770	4050	4015	4010	3885

[a] Average of six cylinders.
[b] Average of two cubes.

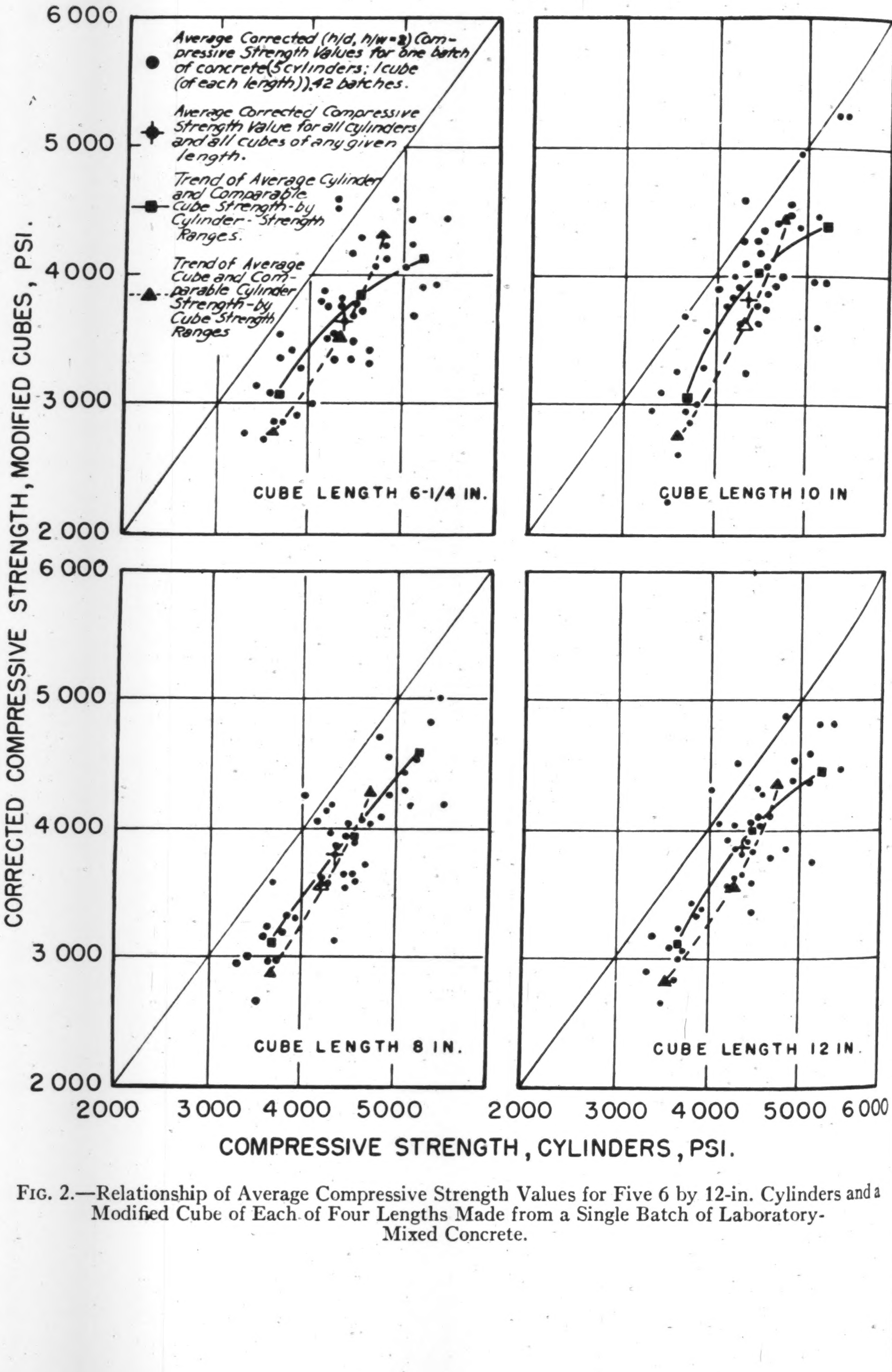

FIG. 2.—Relationship of Average Compressive Strength Values for Five 6 by 12-in. Cylinders and a Modified Cube of Each of Four Lengths Made from a Single Batch of Laboratory-Mixed Concrete.

cylinders by cube-strength groups are given in Table V and plotted in Fig. 2.

DISCUSSION OF RESULTS

Use of Height-Width Correction Factor with Modified Cube Data:

The use of a length-diameter correction factor for core specimens is specified by A.S.T.M. Method C 42 but no comparable height-width factor is specified for use with modified cubes by A.S.T.M. Method C 116. Method C 116, published as tentative in 1935 and adopted as standard in 1936, was supported by test data developed by L. H. Koenitzer. Koenitzer's data[6] indicated that a modified cube, tested on its side, would give a compressive strength value comparable to that obtained by testing a standard cylinder. In 1939 Method C 116 was amended to provide that the top and bottom of the specimen be ground or capped and then loaded. All of the specimens tested to provide the data discussed in this paper were tested with the load applied in the direction of placement of the concrete. It has been the practice of this laboratory to employ a correction factor from the table given in Section 7 of A.S.T.M. Method C 42 to reduce values obtained from modified-cube tests to comparability with 6 by 12-in. cylinders. This practice has been based in part on experience in previous programs of testing conducted here and in part on the relationships reported by Gonnerman.[7] Gonnerman reported that 6-in. and 8-in. cubes tested at ages of 7 days to 1 yr. gave strengths averaging 18 and 13 per cent higher than 6 by 12-in. cylinders.

TABLE V.—LABORATORY CONCRETE.

Average Compressive Strengths of Cylinders and Comparable Cubes from the Same Batches by Cylinder-Strength Ranges, psi.

Cylinder Strength Range, psi.	Number of Batches	Cylinders	Modified Cubes			
			6¼ in. long	8 in. long	10 in. long	12 in. long
3000 to 3995	11	3695	3080	3120	3045	3080
4000 to 4995	25	4525	3815	3920	4065	4015
5000 to 5995	6	5260	4095	4535	4405	4450
Total and Average	42	4410	3660	3800	3845	3820

Average Compressive Strengths of Modified Cubes and Comparable Cylinders from the Same Batches by Cube-Strength Ranges, psi.

Modified Cube Strength Range, psi.	6¼ in. Long Cubes			8 in. Long Cubes			10 in. Long Cubes			12 in. Long Cubes		
	Number of Batches	Cubes	Comparable Cylinders	Number of Batches	Cubes	Comparable Cylinders	Number of Batches	Cubes	Comparable Cylinders	Number of Batches	Cubes	Comparable Cylinders
2000 to 2995	5	2830	3655	4	2895	3695	5	2730	3610	4	2835	3575
3000 to 3995	25	3520	4360	20	3515	4210	20	3625	4325	20	3540	4265
4000 to 5250	12	4305	4830	18	4315	4815	17	4440	4745	18	4355	4760
Total and Average	42	3660	4410	42	3800	4410	42	3845	4410	42	3820	4410

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[6] L. H. Koenitzer, "Modified Cube Compression Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 417 (1934).

[7] H. F. Gonnerman, "Effect of Size and Shape of Test Specimen on Compressive Strength of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 25, Part II, p. 237 (1925). (Reprinted as Bulletin 16, Structural Materials Research Laboratory, Lewis Institute, Chicago.)

All the modified-cube values reported in this paper have been so treated.[8]

The U. S. Engineer Office, Providence, R. I., in December 1943 provided to this laboratory a summary of information obtained by them in a survey of opinions regarding the advisability of correcting modified-cube test values to achieve comparability with 6 by 12-in. cylinder data. Of the eleven authorities quoted in this summary[9] only one stated that in his opinion no correction was needed. Three refer to Koenitzer's work, one stating that it showed that no correction was needed, one stating that no other work was available but making no commitment, and the third pointing out that Koenitzer's data may not apply due to changed procedure. The remaining seven opinions all favor use of a correction factor: two make no recommendation as to what the factor should be, one suggests a reduction of 8 or 10 per cent, two suggest a reduction to 85 per cent, and two suggest the use of the table in Method C 42.

The relationships shown in Fig. 1 for pavement concrete (drilled cores and portions of sawed beams) suggest that if the use of the correction factors did in fact bring the strengths of cores to comparability with 6 by 12-in. cylinders, then the use of similar factors with the modified-cube values has served to bring them closer to parity than would otherwise have been the case. On the other hand, the relationships shown in Fig. 2 for laboratory concrete (6 by 12-in. cylinders and molded beam sections) suggest that the use of the correction factors has served to increase the lack of concordance between values from the two types of specimens.

Length of Portion of Beam Used in Compression Test:

Section 2 of A.S.T.M. Method C 116 requires that portions of broken beams selected for the compression test shall have a length not less than 2 in. greater than the depth of the beam. Hence of those cube specimens tested in Program 2 only those of 6¼-in. length would be unacceptable from this standpoint. The averages shown in Table V indicate that beam sections with a length of from 2 to 4 in. greater than the depth approach more nearly the average strength of the comparable cylinders than do sections of either greater or lesser length. The data, therefore, seem to justify the requirement as to minimum length. The trend toward lower strengths among the specimens of length 6 in. greater than the depth is not understood.

Variation of Comparability with Strength Range:

Analysis of the results of both programs suggest that the relationship of strength values obtained from the types of specimens compared is not a linear function but varies with the strength range of the concrete.[10] The trend of the averages for core and comparable cube strengths shown in Fig. 1 indicates that for core strength ranges up to 5000 psi. the average strengths of the comparable cubes is uniformly close to and slightly greater than the core strengths. Above 5000 psi., however, there is a marked falling off in the average strength values for the comparable cubes, for example, in the 6000 to 7000-psi. core strength range the strength of the comparable cubes is but 86 per cent of that of the cores. The four trends of the averages shown in Fig. 2 for cylinder and comparable cube strengths reveal a similar but less well-developed tendency, perhaps because the highest cylinder strength range for which data are available is that between 5000 and 6000 psi.

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[8] Using the as-tested height-width ratio of the cube to select the proper factor.

[9] Since specific permission has not been obtained from the contributors to this survey to publish their comments the authorship of the individual opinions is not given.

[10] J. C. Pearson, Discussion on "Effect of Height of Test Specimens on Compressive Strength of Concrete," ASTM BULLETIN, No. 120, January, 1943, p. 21, cites cases in which there was an indication that the ratio of height to diameter of specimen does not have so much effect on low-strength mixtures as upon high-strength mixtures and suggests that the ratio might vary with the absolute strength.

CLOSURE

The data given in this paper are presented as information in the hope that they may contribute to the general fund of knowledge on the subject of compressive strength testing of concrete. The author feels that from the data here presented he can make no specific suggestion regarding procedures which might be incorporated in existing methods of calculating compressive strength values. Since no direct comparison of values obtained from 6 by 12-in. cylinders with those obtained from drilled cores is reported, no direct estimate can be made of the validity of the *h/d* correction factor now specified for use with cores.[11] It is felt, however, that data of this sort may ultimately provide the basis for the establishment of such correction-factor relationships as are necessary to bring the values for compressive strength of concrete, regardless of the type of specimen used, to parity with each other.

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[11] James W. Johnson, "Effect of Height of Test Specimens on Compressive Strength of Concrete", ASTM BULLETIN, No. 120, January, 1943, p. 19.

J. Tucker, Jr. "Effect of Length on the Strength of Compression Test Specimens," see p. 976.

DISCUSSION

Mr. H. Walter Leavitt[1] (*by letter*).—Mr. Mather has presented an interesting discussion on height-width factors for concrete specimens, and it is very evident from his presentation that a very large amount of work has been done.

Of possible interest in this connection may be the results of a small research project in this laboratory by Mr. Robert B. Bradford. Mr. Bradford used 2-in. prisms and all of the ratios listed in A.S.-T.M. Standard Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (C 42 – 44)[2] with the addition of 0.6. All of his specimens were made from plastic mortar in which a very careful synthetic grading of the sand was maintained. The results are given below and each factor is the average of 13 individual tests.

h/d	*Factor*
2.00	1.00
1.75	1.024
1.50	1.0058
1.25	0.9546
1.10	0.907
1.0	0.8749
0.75	0.7829
0.6	0.7086
0.5	0.6501

The paper could be greatly improved by the inclusion of suggested strength correction factors similar to the above which might be used in any laboratory, and it is believed that such information would be greatly appreciated by those having to write specifications for the future.

Mr. M. O. Withey[3] (*by letter*).—A set of experiments[4] made at the University of Wisconsin in 1935 corroborates the evidence in Mr. Mather's paper. In the Wisconsin tests all concrete was placed with an internal vibrator. The modified cubes were obtained from portions of 6 by 8 by 72-in. beams. They were loaded on 6 by 6-in. portions of the top and bottom surfaces as molded in the beams. The ratio of least width to height was 0.75 and the lengths of the beam portions so tested were about 10 in. The day before testing, the modified cubes were capped with neat Incor cement tempered with 2 per cent of calcium chloride. Six modified cubes and three 6 by 12-in. cylinders were made per beam. The aggregates were sand and gravel. From concrete with a water-cement ratio of 0.47, by weight, 132 modified cubes and 66 cylinders were tested, and from concrete with a water-cement ratio of 0.62, 204 modified cubes and 102 cylinders were made.

The average ratio of the strength of well-vibrated cylinders to the companion beam fragments was 0.97 for the concrete with water-cement ratio 0.47, and 0.95 for the concrete with water-cement ratio of 0.62. The compressive strengths of the two grades of concrete averaged about 5000 and 3500 psi., respectively.

Additional information on this subject is also afforded by some auxiliary compressive strength tests of mortars used in some reinforced brick masonry column tests[5] at the same institution. The compressive strengths of the mortars were determined in both 2 by 2-in. cubes and in 2 by 4-in. cylinders. Three cubes and three cylinders were tested per batch. Both cylinders and cubes were capped on their top surfaces with a thin layer of plaster of Paris one day before testing. A total of 54 cylinders and 54 cubes was made of mortar of 1 lime:3 cement:12 sand proportions, by weight. The average ratio of the strength of cylinder to strength of cube was 0.99 and the average compressive strength of both types was 2335 psi. Thirty cylinders and 30 cubes were also made of mortar of 1 lime:3 cement:7.5 sand proportions, by weight. The average ratio of the strength of cylinder to the strength of cube was 1.03 and the average compressive strength was 3567 psi.

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[1] Secretary, Maine Technology Experiment Station, Orono, Maine.

[2] 1944 Book of A.S.T.M. Standards, Part II, p. 460.

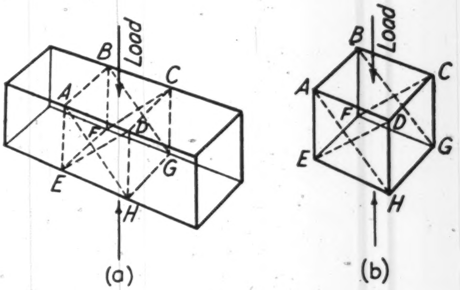
[3] Professor of Mechanics, University of Wisconsin, Madison, Wis.

[4] M. O. Withey, "The Effects of Frequency of Vibration in Making Concrete Beams," *Proceedings*, Highway Research Board, p. 217 (1935).

MR. J. TUCKER, JR.[6] (*by letter*).—Mr. Mather's paper is an addition to the already voluminous proof that there is no "true" compressive strength of a specific concrete. The data illustrate the futility of seeking arbitrary and fixed conversion factors to transform the strength obtained in one type specimen to an equivalent strength which would theoretically be obtained in a specimen of other dimensions. It has been shown[7] that even for the relatively simple transformation into the equivalent strength of specimens differing in length only, the transformation factor will vary with the strength of the concrete, or with the scatter in strength of the material. For performance tests of the material to check specification requirements the particular test specimen should be specified.

Mr. Mather, in discussing the strengths of "modified" cubes in tests made on 6-in. square prisms varying from $6\frac{1}{4}$ in. to 12 in. in length, states that "the trend toward lower strengths among specimens of length 6 in. greater than the depth is not understood," and that the specimens "of length from 2 to 4 in. greater than the depth approach more nearly the average strength of the comparable cylinder than do sections of either greater length or lesser length." As a matter of fact, there is no significant difference between the strengths of the specimen of 8, 10 and 12 in. in length. This can be demonstrated by statistical analysis.

There is, however, a distinct difference in strength between the 6-in. cube and the longer specimens. This may be explained, at least partially, by the statistical theory of the strength of materials, assuming that compressive failure occurs in a plane or planes inclined to the axis. Referring to the accompanying Fig. 1(*a*), failure in the 8-, 10-, and 12-in. specimen can occur in two planes (*ABGH* and *CDEF*) whereas in the cube, failure can occur not only in these two planes, but also in two planes (*ADGF* and *BCHE*, not shown) through an axis perpendicular to the axis of the planes of failure for the longer specimens (see Fig. 1(*b*))



(a) (b)

FIG. 1

From the statistical theory of the strength of materials[7,8], the strength of the true cube may be computed from the strength of the longer specimen (modified cube) if we know the standard deviation of the strength of the longer specimen. This standard deviation may be obtained from Mr. Mather's data as follows. If we assume no significant difference in strength between the specimens of 8, 10, and 12 in. in length, the data in Table IV on these three lengths for each batch may be viewed as tests from the same universe. Using the method of ranges of A.S.T.M. Manual for the Presentation of Data, we determine the difference, for each batch, between the highest and the lowest value in the last three columns of Table IV. The mean difference for all 42 batches is found to be 402 psi. From the Manual, this equals 1.693 σ_1; hence σ_1, the standard deviation for individual specimens, is 238 psi.

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[5] M. O. Withey, "Tests on Reinforced Brick Masonry Columns," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 387 (1934).

[6] Chief, Cement and Concreting Materials Section, National Bureau of Standards, Washington, D. C.

[7] J. Tucker, Jr., "Effect of Length on the Strength of Compression Test Specimens," see p. 976.

[8] J. Tucker, Jr., "The Effect of Dimensions of Specimens Upon the Precision of Strength Data," see p. 952.

Now from Tippett's tables[8,9] the theoretical reduction in strength for $n = 2$, is $0.56\sigma_1$, or $0.56 \times 238 = 136$ psi. The actual difference in strength is 162 psi. Thus the theory explains 82 per cent of the strength difference.

Mr. Bryant Mather (*author's closure, by letter*).—The test data presented by Messrs. Leavitt and Withey form a welcome addition to the author's paper. The author is particularly grateful to Mr. Tucker for his valuable statistical discussion which provides considerable theoretical background for the proper appreciation of the significance of the data set forth in the paper. With regard to Mr. Leavitt's observation that the paper could be greatly improved by the inclusion of suggested strength correction factors as information that would be greatly appreciated by those having to write specifications, the author can only restate his feeling that the data as presented permit him to make no such specific suggestion. Mr. Tucker suggests that it is futile to seek such arbitrary and fixed conversion factors and feels that for performance tests to check specification requirements, the particular test specimen should be specified. The author is in complete agreement with the suggestion that a strength requirement in a specification must also specify the type of test specimen and that conformity with such a specification cannot be determined by transformation of values obtained by testing specimens of other types. It remains, however, the belief of the author that as the relationships between values obtained from the testing of specimens of different types and different strength ranges become better known, these relationships may prove of considerable assistance to workers who desire to correlate data from tests performed on specimens of different types.

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[9] L. H. C. Tippett, "On the Extreme Individuals and the Range of Samples Taken from a Normal Population,' *Biometrika*, published by University College, London, England, Vol. 17, p. 364 (1925).

AUTOMATIC ACCELERATED FREEZING-AND-THAWING APPARATUS FOR CONCRETE

By Charles E. Wuerpel[1] and Herbert K. Cook[1]

Synopsis

A detailed structural and operational description is given of a newly developed apparatus for automatically and rapidly freezing and thawing $3\frac{1}{2}$ by $4\frac{1}{2}$ by 16-in. concrete specimens. The temperature of the capacity load of 102 specimens is reversed from 42 F. to 0 F. and from 0 F. to 42 F. in a 2-hr. cycle. Typical results of tests to determine the influence of aggregate type on the durability of concrete made with and without an air-entraining admixture are presented to illustrate the practicability of using the apparatus for acceptance testing based on freezing and thawing.

A standard procedure for the determination of the potential resistance of concrete to frost action and to thermal shock has been a goal of the concrete testing fraternity ever since durability was recognized as an economic and structural problem. The importance of the problem has resulted in the appointment of numerous committees of testing engineers for study and recommendation; numerous separate researches have been conducted by private, educational, and public agencies, and numerous methods and devices have been used and are now in use in an effort to provide an adequate procedure for the test.

It is recognized that the resistance of concrete to frost action is a complex function of the many variables potentially present in the composition of the hardened product and in the method of test. The chemistry of the cement, the degree of hydration, the quality of the hydration product; the nature, grading, and thermal properties of the fine and coarse aggregate; the homogeneity of the mixture are some of the variables which might be termed *controllable* or *voluntary*. The rate of cooling, the degree of cooling, the rate of warming, the degree of warming, the shape of the specimen, the relative degree of moisture saturation of the aggregate and of the matrix are independent variables which affect the history of the resistance of the *controlled* concrete to frost action.

It is patently impossible to duplicate in the laboratory conditions of weathering to which any particular element of a structure will be exposed. Some structures will be subjected to many and frequent reversals of freezing and thawing due to exposure to sunlight and mild temperature in the daytime and temperatures below freezing at night—under highly varying conditions of moisture saturation. The degree and depth of frost penetration of each cycle will be functions of the mass of the concrete and the ambient temperature. Other structures will be subjected to continuous very low temperature throughout long periods during which the surface may or may not thaw as affected by sunlight, snow cover, or rain. Still other structures are exposed to various degrees of temperature and moisture at and near the water line. In some cases, freezing may be sudden and severe, in others very slow and either mild or severe. Therefore, it is hardly within the scope of the imagination that a standard test procedure is possible which will permit definite correlation with service of the structure. It appears to be obvious, too, that a procedure which requires months for the development of significant data is impractical since the case is unusual rather than ordinary where a period in excess of 28 days is available for testing the quality of materials proposed for use in a particular project. It appears to the authors that the goal should be limited to a procedure which is highly reproducible and sufficiently severe and rapid to permit determination of the potential relative durability of the concrete in question in sufficient time to make the data useable on the basis of an acceptance test.

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[1] Engineer-in-Charge and Engineer, respectively, Central Concrete Laboratory, Corps of Engineers, U. S. Army, Mount Vernon, N. Y.

It was the thought of the senior author that a procedure should be devised in which all of the conditions of the test would be constant and in which the results should be available within a period of 28 days after receipt of the materials in question at the laboratory. In pursuance of this thought it was decided to devise an apparatus which: (*a*) would be entirely automatic and require no movement of the test specimens during the desired reversals of temperature, (*b*) would develop thermal gradients of a severe but highly reproducible nature, and (*c*) would maintain a constant moisture saturation influence. The premises upon which the mechanical design was based were: (*a*) reduction in specimen temperature from 42 ± 2 F. to 0 ± 2 F. in 1 hr., (*b*) elevation of the specimen temperature from 0 ± 2 F. to 42 ± 2 F. in the second hour, (*c*) repeated reversals of this cycle to the number desired, (*d*) immersion of the specimen at all times in water, and (*e*) uniform thermal effects on all specimens tested.

The specimen decided on was $3\frac{1}{2}$ by $4\frac{1}{2}$ by 16 in. in dimension. Such a specimen would: (*a*) lend itself well to determination of dynamic modulus of elasticity by vibro-electronic means, (*b*) permit the use of coarse aggregate of 1 or $1\frac{1}{4}$ in. maximum size, and (*c*) allow a maximum number of specimens to be tested in a given cubic volume of space.

It was recognized that the extraneous variables introduced during the manufacture and preliminary handling of the specimens would still be latently present and that no device could give assurance of their elimination or control. Elimination of extraneous variables inherent in manufacture can be obtained only by extremely rigid adherence to a highly standardized preparation, making and storage procedure in which even the humidity of the air in the mixing and molding zone exerts a noticeable effect on the results. Such a manufacturing procedure is beyond the scope of this paper.

DESCRIPTION OF APPARATUS

The major apparatus developed in accord with the ideas described in the foregoing consists essentially of three insulated tanks; one for the cold fluid, one for the thawing fluid, and one for the specimens; with means for refrigerating the cold fluid and heating the thawing fluid, and the necessary pumps, valves, and controls to circulate the solutions through the specimen tank at the required temperatures, time intervals, and rates of flow. A schematic arrangement of the apparatus, showing the principle of operation is shown in Fig. 1. The apparatus will reduce the temperature of one hundred and two $3\frac{1}{2}$ by $4\frac{1}{2}$ by

16-in. concrete specimens to 0 ± 2 F. in 1 hr. and will raise their temperature to 42 ± 2 F. in the next hour. It will automatically repeat the above 2-hr. cycle for any desired number of cycles without attention. The various units of the apparatus are described in detail below:

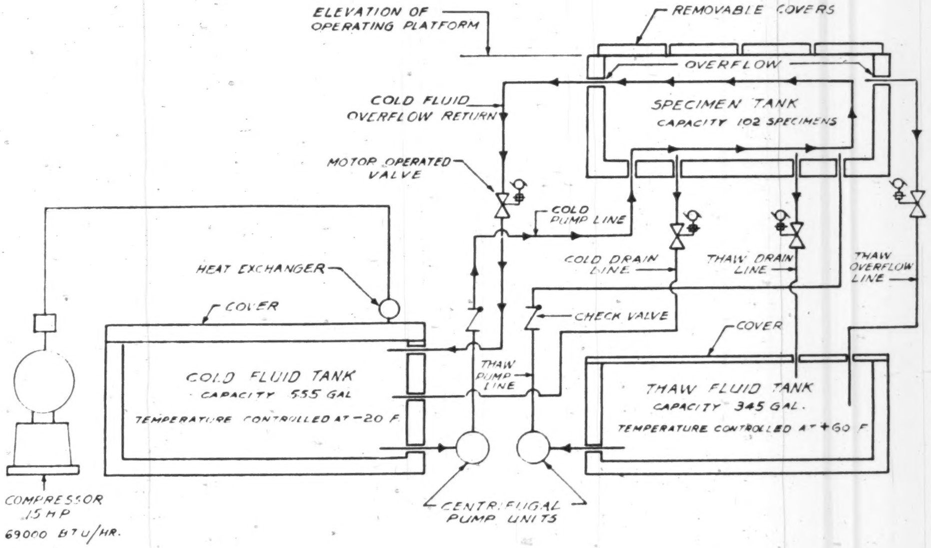
ELEVATION OF OPERATING PLATFORM
REMOVABLE COVERS
OVERFLOW
COLD FLUID OVERFLOW RETURN
SPECIMEN TANK
CAPACITY 102 SPECIMENS
MOTOR OPERATED VALVE
COLD PUMP LINE
COLD DRAIN LINE
THAW DRAIN LINE
THAW OVERFLOW LINE
HEAT EXCHANGER
COVER
CHECK VALVE
COVER
COLD FLUID TANK
CAPACITY 555 GAL
TEMPERATURE CONTROLLED AT −20 F
THAW PUMP LINE
THAW FLUID TANK
CAPACITY 345 GAL.
TEMPERATURE CONTROLLED AT +60 F
COMPRESSOR
15 HP
69000 BTU/HR.
CENTRIFUGAL PUMP UNITS

FIG. 1.—Schematic Arrangement. Automatic Freezing and Thawing Unit (Showing Circulation of Cold Fluid)

Freezing-and-Thawing Solutions:

A solution containing 60 per cent specially denatured alcohol (Formula 3A)[2] and 40 per cent water is used for both the cold and thaw fluids. Alcohol was used as the heat transfer medium because it permitted construction of the apparatus with less critical and less expensive materials than would have been required for more corrosive brine solutions. Solutions for both freezing and thawing are used at the same concentrations because of the impossibility of preventing some intermixing in the specimen tank. The solution of 60 per cent alcohol and 40 per cent water has a freezing point of approximately −40 F. While the average temperature of the cold fluid is −20 F. the refrigeration plate temperatures are as low as −35 F. and therefore require a solution that will not freeze at less than −40 F. Approximately 540 gal. of alcohol and 360 gal. of water were required to charge the system.

Cold Tank and Refrigeration Equipment:

The cold tank is lined with 16-gage galvanized iron with welded joints and is insulated with 8 in. of corkboard covered with 20-gage galvanized iron. The inside dimensions of the tank are 21 in. depth, 60 in. width, and 126 in. length. It contains twenty-five 12 by 108-in. refrigeration plates having double radiation surfaces. The plates are assembled in units of five, each unit being controlled by a separate multiport thermostatic expansion valve. This method of as-

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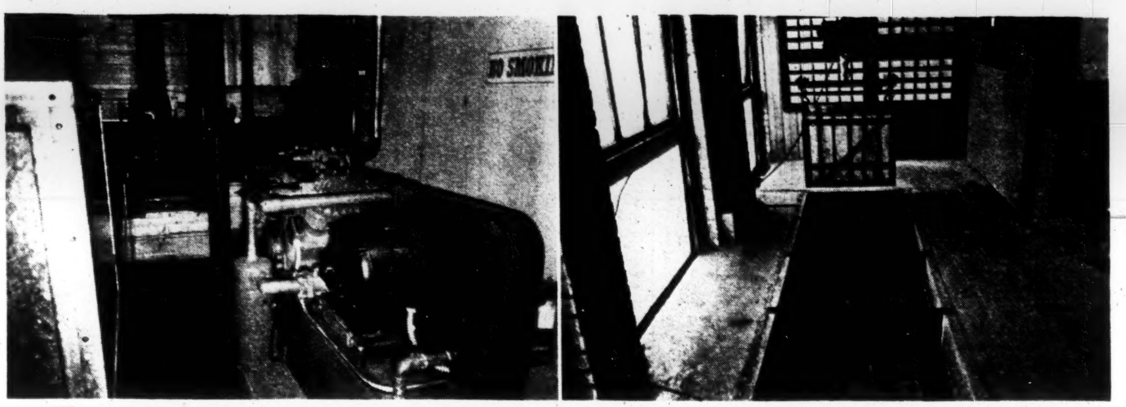
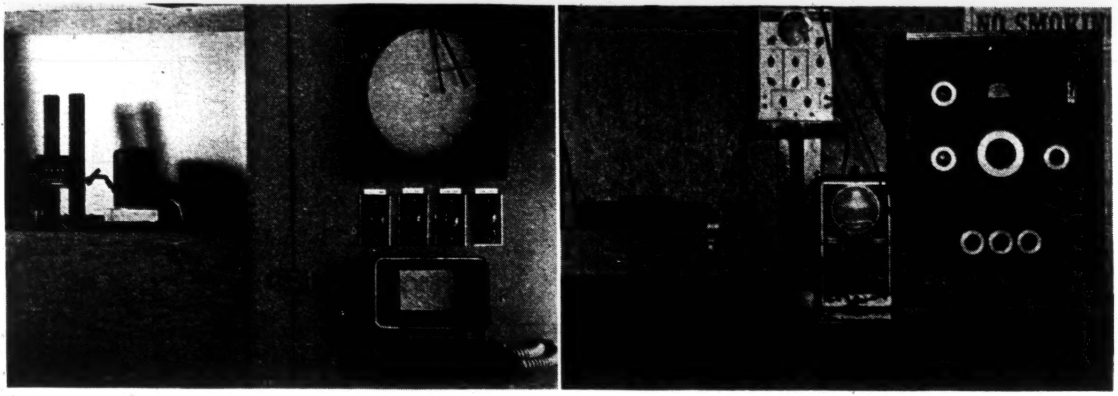
[2] Five gallons methyl alcohol to 100 gal. ethyl alcohol, 95.17 per cent ethyl alcohol by volume.



(*a*) Lower Level. Shows Tanks, Condensing Unit and Circulation Pipes.

(*b*) Upper Level. Shows Specimen Tank and Method of Specimen Removable.



(*c*) Shows Timer, Solution Temperature Recorder and Cycle Counter.

(*d*) Shows Vibro-Electronic Apparatus with Specimen (*S*) in Place.

FIG. 2.—Automatic Accelerated Freezing and Thawing Apparatus.

sembly and operation will maintain the required temperatures even if one unit is not functioning because of a frozen expansion valve. An insulated chamber is provided on the top of one end of the tank to house the expansion valves, refrigerant piping, solenoid valve, and thermostat. The refrigeration is performed by a 15-hp., 220-v., 60-cycle, 3-phase, water-cooled condensing unit using Freon F-12 as the refrigerant, and has a capacity of 69,000 Btu. per hr. The capacity of the cold tank with plates installed and when filled to within 2 in. of the top is approximately 550 gal. Solution is removed from the bottom of the tank through a 2½-in. pump line and is returned at the top on the opposite end of the tank through a 3-in. gravity flow line from the specimen tank. This method of inlet and discharge provides ample circulation across the refrigeration plates and mechanical agitation is not necessary. A view of the condensing unit, the three tanks, and a portion of the 3-in. cork-insulated circulation pipes is shown in Fig. 2(*a*).

Thaw Tank and Heating Equipment:

The thaw tank is also constructed of 16-gage galvanized iron, with 4 in. of rock wool insulation held in place with fir tongue-and-groove sheathing. The inside dimensions of the tank are 26 in. depth, 35 in. width, and 108 in. length. Twelve 1000-w., 220-v., immersion heaters are installed across the width of the tank 4 in. from the bottom and 8 in. apart. The heaters are controlled by a thermostat set at 60 F. which actuates a 40-amp., 220-v., 3-phase magnetic contactor which operates the heaters. The solution in the thaw tank is maintained at a depth of 21 in. when not in circulation and at that depth the capacity of the tank is approximately 345 gal. The arrangement and size of the circulation lines are the same as for the cold tank.

Specimen Tank, Racks, and Containers:

The specimen tank is constructed of 12-gage galvanized iron with welded joints and is insulated with 8 in. of corkboard covered with fir tongue-and-groove sheathing. The inside dimensions of the tank with covers in place are 24 in. depth, 34 in. width, and 108 in. length. Four removable covers containing 8 in. of corkboard provide access to the tank for insertion or removal of specimens. The covers are of the refrigerator-door type and the edges are supported by steel channels covered with ¼-in. Bakelite running across the width of and flush with the top of the tank. The Bakelite is a frost breaker and prevents freezing of the covers to the top of the tank. The tank also has a ¼-in. Bakelite frost breaker running entirely around it at a point just below the elevation of the bottoms of the covers when they are in place, to prevent the formation of frost between the walls of the tank and the covers. There are two 3-in. drains in the bottom of the tank, centered and at the one-third points of the tank length. Two 3-in. overflow outlets are provided on one wall of the tank centered 17½ in. from the bottom and also on the one-third points of the tank length, which give a solution depth of 19 in. when solution is in circulation. Solution is pumped into the specimen tank through a 2½-in. header pipe running along the bottom of the tank, on the same side as the overflow outlets. The header pipe has three openings equally spaced along the tank length, the openings being 1, 1½, and 2 in., respectively, to equalize their rate of discharge. The openings are directed slightly downward from the horizontal to cause a circular flow of solution across the lower portion of the tank and specimens, up to the opposite side, and back across the top portion to the overflow outlets.

FIG. 2.—Automatic Accelerated Freezing and Thawing Apparatus.

The concrete specimens are placed vertically in individual 24-gage galvanized iron containers with covers, the inside dimensions of the containers being $3\frac{3}{4}$ by $4\frac{3}{4}$ in. by 21 in. deep. Four racks constructed of steel angle, strap, and rod, to form an open structure through which solution can circulate freely are used to hold the individual containers. The racks are identical in size, the dimensions being such that they will fit through any of the four openings in the specimen tank. Each rack will hold 24 containers, the containers being kept equally spaced from each other by means of a grill at the top and another several inches from the bottom of each rack. The rack also keeps the containers 1 in. from the bottom of the specimen tank. The four racks will accommodate 96 specimens but since one of the openings in the specimen tank was purposely made larger than the others to accommodate odd sizes of specimens such as cylinders, there is room for six more specimens in this section making the total capacity 102 specimens.

The top of the specimen tank is flush with the floor of the mezzanine section of the laboratory in which the testing of the specimens is conducted. The racks are lowered into the specimen tank by means of a $\frac{1}{2}$-ton electric hoist suspended from a monorail trolley the track of which is attached to the ceiling of the mezzanine over the long axis of the specimen tank. Figure 2(*b*) shows the specimen tank with covers removed and with one rack suspended from the electric hoist to demonstrate the method of specimen handling; the cards on the bulletin board in the background contain pertinent information relative to each specimen and the arrangement of the cards on the board indicates the location of each specimen in the tank.

Pumps, Valves, and Controls:

Circulation of the cold and thaw fluids is accomplished by two centrifugal pumps rated at 80 gal. per min. at a 15-ft. head. The pumps are belt-driven by 1-hp., 220-v., 3-phase, explosion-proof motors. Belt-driven motors were required because of the necessity of insulating the pumps with cork to prevent frost formation which could not be satisfactorily accomplished with direct-connected motor pump units. Since only one solution is circulated at a time both pumps discharge into a common $2\frac{1}{2}$-in. pipe leading to the distribution header inside the specimen tank. Leakage of solution from one pump line to the other is prevented by a check valve and a motorized valve installed ahead of each pump. Common pipes are also employed in the overflow and drain lines from the specimen tank, the solution being directed to the proper return tank by proper valving through four electrically-operated globe valves, one valve each for the cold and thaw fluid drain lines, and one each for the cold and thaw fluid overflow lines. Since the specimen tank is at a higher elevation (approximately 4 ft.) than the cold and thaw fluid tanks, overflow and drainage from the specimen tank is accomplished by gravity flow through 3-in. galvanized-iron pipes. All pipe lines are covered with brine thickness cork pipe covering.

Since all valves and pumps are electrically operated, circulation of the solutions is made entirely automatic by means of a 2-hr., seven-circuit timer and a Veeder-Root predetermining counter. The timer consists of a series of properly shaped cams mounted on a common shaft driven by a 2-hr. electric clock motor. As the shaft revolves the cams will open and close the various circuits in their proper sequence. The clock motor is wired in series with the predetermining counter which can be set at any desired number of cycles and will open the clock circuit and thereby stop all operation of the freezing-and-thawing apparatus when the desired number of cycles has been reached. The counter is of the ratchet-drive type as compared to the revolution type and is actuated by a lever arm on a small hydraulic operator similar to the operators on the cold and thaw fluid pump valves. The operator is connected to the seventh circuit on the timer and will make one count at the end of each thawing cycle. Fig. 2(*c*) shows the counter and its operator and also shows the timer with the cover open. The seven circuits controlled by the timer and the sequence in which they operate are given below:

Elapsed Time			Circuit Number	Contact	Operation
Hr.	Min.	Sec.			
0	0	0	1	on	Open cold overflow and cold pump valves.
0	1	0	2	on	Start cold fluid pump.
0	55	0	2	off	Stop cold fluid pump.
0	55	0	3	on	Open cold drain valve.
1	0	0	3	off	Close cold drain valve.
1	0	0	1	off	Close cold overflow and cold pump valves.
1	0	15	4	on	Open thaw overflow and thaw pump valves.
1	1	0	5	on	Start thaw fluid pump.
1	55	0	5	off	Stop thaw fluid pump.
1	55	0	6	on	Open thaw drain valve.
1	59	30	7	on	Start cycle counting mechanism.
2	0	0	6	off	Close thaw drain valve.
2	0	0	4	off	Close thaw overflow and thaw pump valves.
2	0	0	7	off	Stop cycle counting mechanism.

Circuits Nos. 2, 3, 5, and 6 also operate pilot lights which indicate the respective phases of operation of the apparatus. The pilot lights can be seen directly above the timer in Fig. 2(*c*).

Liquid Level Safety Controls:

Without automatic liquid level control devices it is possible for any of the three tanks to be filled to overflowing because of failure of any of the electric valves to operate or because of transfer of solution between the cold and thaw fluid tanks. In this connection it has been noted that there is a tendency toward the slow transfer of solution from the cold tank to the thaw tank. This tendency is believed to be due to the fact that the viscosity of the cold fluid is greater than that of the thaw fluid resulting in slower and more incomplete draining from the specimen tank; this causes a cumulative slow transfer of solution to the thaw tank and requires periodical retransfer back to the cold tank at 2- or 3-day intervals. Any difference in the level of the cold and thaw drain valves or the cold and thaw overflow valves will also cause a cumulative transfer between the cold and thaw fluid tanks, the transfer being in the direction of the lowest valve. Overflow and loss of alcohol solution by either of the above means is prevented by a liquid level control probe installed in each tank at a point 1 in. below the point where overflow might occur. In the event that solution touches any of the three probes an electric circuit will be completed which after amplification through a vacuum tube will operate a relay, closing all valves and stopping the pumps, maintaining the solutions at whatever level they may be. The relay is of the double-throw type and is wired to operate a warning light whenever the probe circuits are closed. Correction of the trouble and restarting of freezing-and-thawing operations can only be made by throwing a switch which by-passes the probe circuits, permitting correction of the trouble by the proper transfer of solutions. Since the by-pass switch eliminates the protection afforded by the probe circuits it is of the type which requires a key for its operation to prevent its unauthorized or accidental manipulation.

Temperature Records:

The temperature of the cold and thaw fluids and the temperature of the circulating fluid in the specimen tank are recorded on the chart of a three-pen seven-day recording thermometer. The thermometer is shown in Fig. 2(*c*). The temperatures of the concrete specimens are recorded on a recording potentiometer by means of a thermocouple embedded in the center of a concrete specimen installed in the specimen tank, with sufficient lead wire to reach the potentiometer. The normal operating temperatures of the cold and thaw fluids and the temperature change of the thermocouple specimen for three complete cycles are shown in Fig. 3. The sudden temperature rise of the thaw fluid and its sharp drop at the start of the thawing cycle is the result of stratification due to the absence of mechanical agitation in the thaw fluid tank causing higher temperatures at the top of the tank. When circulation is started, the fluid level in the tank is drawn down and the warmer portion passes across the bulb as indicated by the sudden temperature rise. The sudden drop is of course caused by the lowering of the temperature of the solution as it gives up heat to the frozen specimens.

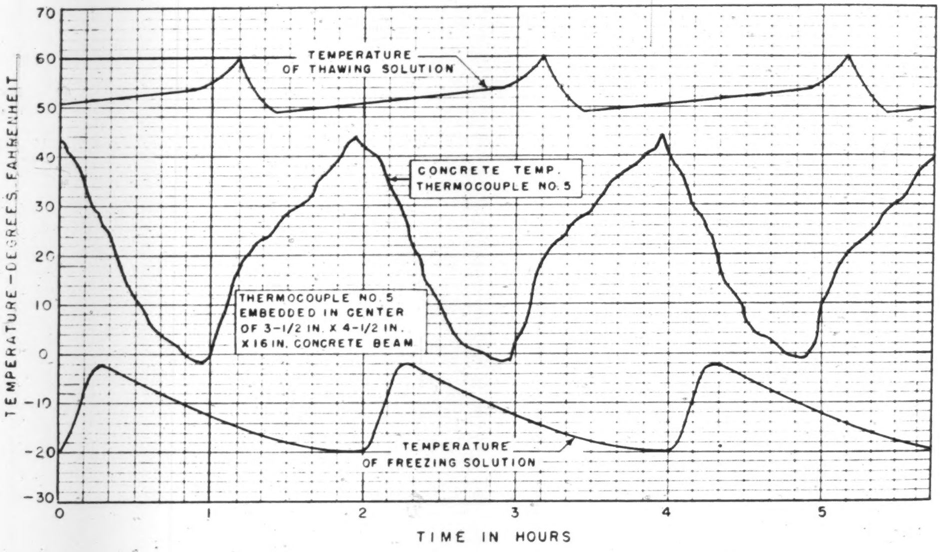


FIG. 3.—Typical Freezing and Thawing Cycles—Automatic Freezer.

OPERATION OF EQUIPMENT AND TESTING OF SPECIMENS

Other than routine checking of liquid levels, solution concentrations, and general mechanical operation, the apparatus requires no attention other than setting the counter to the number of cycles desired. The apparatus has the distinct advantage of requiring no handling of specimens except when actual testing is required and provides a means of rapidly obtaining a large number of highly uniform exposure cycles without attention.

The normal test procedure of this laboratory is to store the specimens in moist air at 70 ± 2 F. for nine days after making before subjecting them to the accelerated freezing-and-thawing test. It is also customary to have control specimens for each group of test specimens. The dynamic modulus of elasticity (E) of both the test and control specimens is determined by vibro-electronic methods at the 9-day age. The apparatus used in determining the dynamic E is shown in Fig. 2(*d*).

The test specimens are normally removed from the apparatus and their dynamic modulus again determined at 3 cycles, 10 cycles, and thereafter at intervals not exceeding 27 cycles. All results are expressed in terms of relative E which is the percentage change in dynamic E; the dynamic E at 0 cycles (9-day age) being taken as 100 per cent. Freezing-and-thawing cycles are continued until the relative E has decreased to 50 per cent of that at the 9-day age or until the test has been continued for the specified number of cycles desired. When the freezing-and-thawing exposure has been completed and the final determination of dynamic E has been made, the specimens are tested in flexure in a damp condition, using mid-point loading. The dynamic E and flexural strength of the control specimens are determined at the 28-day age. The durability factor (*DFE*) based on dynamic modulus of elasticity, and the durability factor (*DFM*) based on the modulus of rupture are calculated from the following formulas:

$$DFE = \frac{PN}{M}$$

where:

DFE = durability factor in per cent of the dynamic modulus of elasticity at 0 cycles,

P = relative dynamic modulus of elasticity of 50 per cent or greater,

N = number of cycles at which P reaches 50 per cent or the ultimate number of cycles of the test if P does not reach 50 per cent prior to the ultimate cycle, and

M = ultimate number of cycles of the test.

$$DFM = \frac{M_2}{M_1} \times 100$$

where:

DFM = durability factor in per cent based on the modulus of rupture of stored specimen(*s*),

M_2 = modulus of rupture of the frozen and thawed specimens in pounds per square inch, and

M_1 = modulus of rupture of the stored control specimens in pounds per square inch.

RESULTS

The automatic freezing-and-thawing device described above was completed in February, 1945 and has been in continuous full-scale operation since that time. An entirely similar but smaller capacity (25 specimens) device was placed in operation in August, 1944 and has been operated continuously thereafter. More than 700 specimens have been tested in the two devices embodying numerous variables of aggregate, cement, air-entraining admixture, and water-cement ratio. The results of a major portion of these tests have been or will be published elsewhere.[3] The principal purpose of this paper is to describe the apparatus and its manner of operation, only representative results of certain test programs will be described to demonstrate typical performance of various types of concrete in the test.

Influence of aggregate type on the durability of concrete made with and without an air-entraining admixture is

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[3] Charles E. Wuerpel, "Some Effects of Air-Entrainment and Coarse Aggregate Type on the Properties of Concrete" to be published by the National Crushed Stone Assn.

Charles E. Wuerpel, "Laboratory Studies of Concrete Containing an Air-Entraining Agent" to be submitted to the American Concrete Institute for publication.

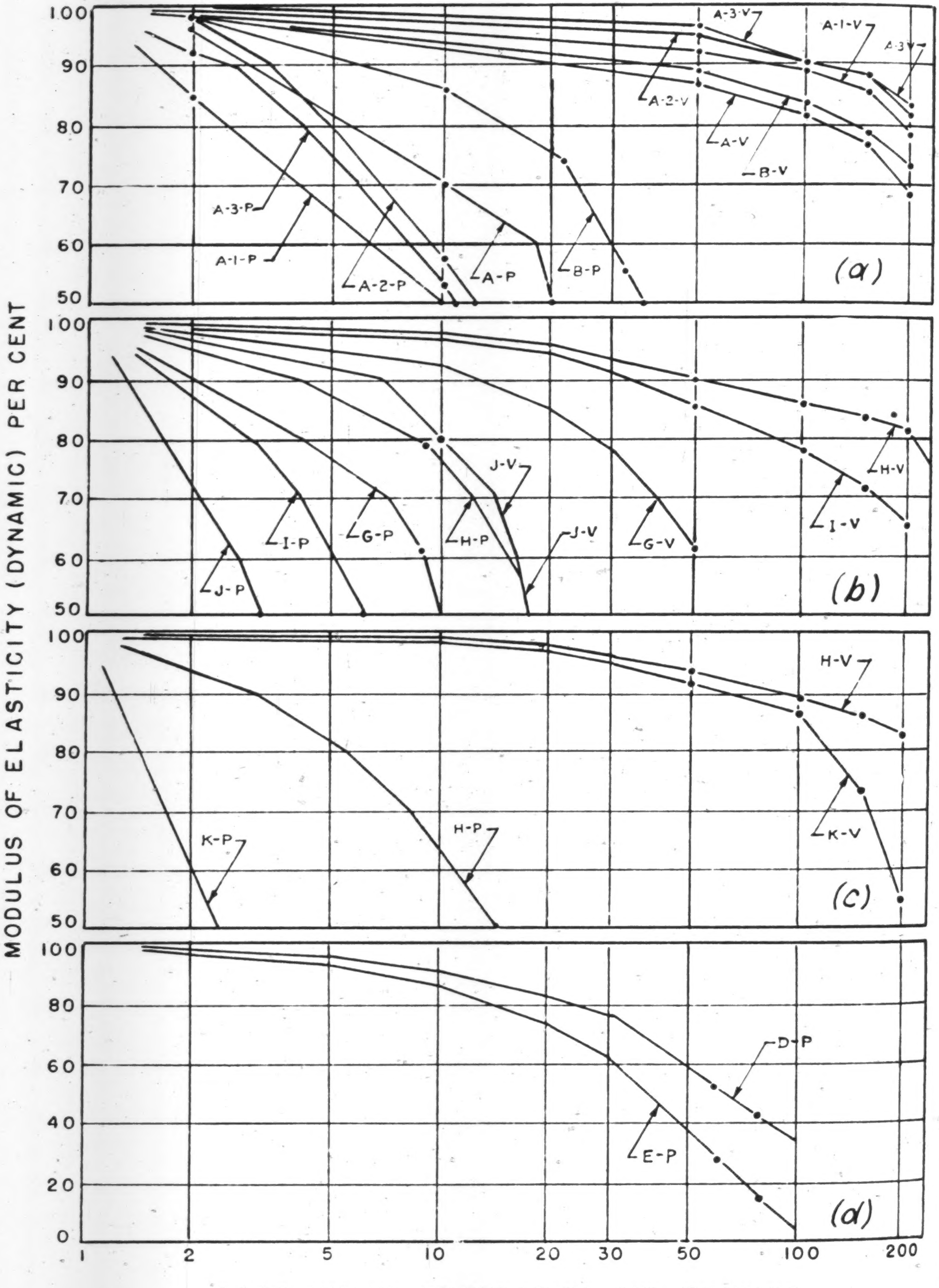

FIG. 4.—Influence of Aggregate Type on Durability of Concrete Made with and Without an Air-Entraining Admixture.

illustrated in Fig. 4. Each of the curves represent the average results of three runs made on different days. The series of tests shown in Fig. 4(*a*) was to determine the effect of ball-milling as a means of improving the durability of fine aggregate containing an appreciable amount of badly weathered material. A highly durable trap rock was used as coarse aggregate. The symbol *A* indicates the unmilled material and the numerical symbols 1, 2, and 3 indicate samples of material milled for increasing periods of time. The symbol *B* indicates a sand of normally good service and laboratory tests record. The symbols *P* and *V* indicate type II plain cement alone and the same cement used with an air-entraining admixture, respectively. The test indicated that the sand is considerably less durable than the reference sand when tested with plain cement and that the milling process did not improve durability. However, when tested in the presence of the admixture, the difference between the unmilled sand and the reference sand was reduced to a minimum and the milling process caused a marked improvement in durability.

The series of tests shown in Fig. 4(*b*) was to determine the relative durability of four types of coarse aggregate. The symbols *G*, *H*, *I* and *J* indicate the coarse aggregates and the symbols *P* (type II plain cement) and *V* indicate the presence or absence of the air-entraining admixture. The tests with plain cement were in close accord with results obtained in the magnesium sulfate soundness tests, service record, and mineral properties. The tests made in the presence of the air-entraining admixture indicate a similar but much more apparent difference in relative durability, plus the indication that the concrete made with coarse aggregate *I* approached that of the highly-durable trap rock *H*.

The series of tests shown in Fig. 4(*c*) was for the purpose of determining the durability of coarse aggregate *K* as compared to the durable aggregate *H*. The results indicate the anticipated relative results and, in addition, that the use of the air-entraining admixture very materially improved the relative durability of the concrete containing aggregate *K*. Incidentally, the results indicated for aggregate *H* in this series are in close accord with those indicated in Fig. 4(*b*) although the tests were conducted at different times.

The series of tests shown in Fig. 4(*d*) was conducted to determine the relative durability of fine aggregate *E* as compared to known-to-be durable fine aggregate *D*. The relationship of the results are in accord with service record and other laboratory tests. No admixture was used in this series. The cement in this series was type III and the coarse aggregate was trap rock *H*.

SUMMARY

The automatic freezing-and-thawing apparatus has been found to operate satisfactorily and has given results to date of a degree of reproducibility that appear to offer an acceptable means for conducting accelerated durability tests in a period suitable for "acceptance" determinations on the materials used in concrete. Such a method of test is believed to be preferable to other available tests, such as the accelerated soundness tests of aggregate, because it permits *materials for concrete* to be tested *in concrete*. This is important, because there is evidence that some materials behave quite differently when tested in a fully unconfined condition than they do when rigidly confined in concrete.

The apparatus is relatively costly, the large unit costing approximately $10,000 and the small unit approximately $3000 but the value of the test is believed to be appreciably greater than that of the value obtained by determining the "strength" of concrete cylinders in $10,000 compression testing machines.

THE EFFECT OF REPEATED LOADING ON THE BOND STRENGTH OF CONCRETE [1]*

By C. W. Muhlenbruch [2]

Synopsis

A repeated-loading machine which accommodates six pull-out type specimens to which load is applied through levers at a rate of 52,000 repetitions per 24 hr. is described. Rectangular specimens varying from 5 to 10 in. in length and using a ⅝-in. round reinforcing bar were subjected to as many as 5,000,000 cycles of load. It has been found that, as the number of repetitions of loading increases, the static pull-out strength decreases. The ratio of the static pull-out strength after 5,000,000 cycles to the static pull-out strength of pilot specimens not subjected to repeated loading was found to be about 50 per cent for specimens 5 in. long and subjected to a load equal to approximately 50 per cent of the static pull-out load. When the load applied to the specimen was reduced to 37 per cent, this ratio increased to approximately 87 per cent. Values are also reported for the other embedment lengths. Early investigational work of the fatigue strength of both plain and reinforced concrete is briefly summarized in the paper and an extensive bibliography is given.

Statement of Problem:

Considerable investigation has been made to determine the fatigue strength, or strength under repeated loading, of concrete, both plain and reinforced. Other investigations have been made to study the static bond strength of embedded reinforcing bars using the conventional "pull-out" type of specimen. Investigators have more recently studied the actual stresses in the reinforcing bar over the entire length of embedment. No attempt has been made, however, to determine the effect of repeated loading on the magnitude or distribution of these stresses, nor has the author been able to discover any work done by others to determine the effect of repeated loading upon the ultimate bond strength.

It is realized that under most design conditions both the concrete and the reinforcing bar are in tension. The test method as outlined here incorporates concrete which is in compression while the bar is in tension. While this condition may not be the most satisfactory, it at least will give a satisfactory approach to the general problem. Gilkey, Chamberlin, and Beal (**1**)[3] have shown that "Whether the steel happens to be surrounded by tensile concrete, as in a beam, or by compressive concrete, as in a pull-out specimen, seems to have no significant effect either on the nature or magnitude of the bond developed."[4] While this conclusion resulted from a study of specimens that were somewhat different from the short pull-out type used for these repeated-loading tests, it is some evidence in support of the fact that the approach made to the basic problem in the tests herein reported is satisfactory.

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[*] Manuscript received too late for distribution before publication in *Proceedings*. Any discussion that is received for this paper will be published in the ASTM Bulletin and the 1946 *Proceedings*.

[1] Summary of a thesis submitted in partial fulfillment of the requirements for the Master of Science Degree in Civil Engineering, Carnegie Institute of Technology.

[2] Associate Professor of Civil Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see, p. 845.

[4] Page 7, conclusion 20, of reference (**1**).

Object of Investigation:

The purpose of this investigation was twofold, as follows:

1. To design and construct a repeated-loading testing machine that would give satisfactory performance.
2. To determine the influence of repeated loading on the bond strength of steel reinforcing bars embedded in concrete of a constant mix, water-cement ratio, and type and grade of aggregate and cured for a standard length of time.

EARLY INVESTIGATIONAL WORK

The only work relative to this investigation and thus far reported has been mainly concerned with the effect of repeated loading upon the properties of various mortars and concretes. The first work of this kind was reported by Van Ornum (2) in 1903. Two-inch cubes of neat portland cement, moist-cured for 4 weeks, were found to fail after 5500 cycles of a load of 55 per cent of their static compressive strength. Seven-inch cubes of concrete, the mix of which was not given, showed about the same result.

Again, in 1907, Van Ornum (3) reported the results of a continuation of the previous work. In a lengthy investigation he used a 1:3:5 mix by volume and specimens moist-cured for 1 month or for 1 yr. Loads were applied from four to eight times per minute in a testing machine converted to this use, and varied from a minimum to a maximum. Tests were also made on reinforced-concrete beams and on a modified-impact, repeated-load specimen. The test results indicated that the endurance limit for compression is about 50 to 55 per cent of the static compressive strength.

Van Ornum tested reinforced-concrete beams at the same speed as the compression specimens. These tests indicated that the endurance limit of the beams was not more than 50 per cent of the static breaking strength of the beams.

Van Ornum also made a modified repeated-loading test for bond strength. A specimen 4 by 4 by 15 in. long was cast with a $\frac{5}{8}$-in. plain round bar embedded parallel to the length and having its center 1 in. from the face of the concrete. This block was then supported as a beam with the reinforcing bar in the tension side of the specimen. A heavy hammer, cushioned with an oak bearing block, struck the specimen at mid-span and delivered an estimated 740 in-lb. of energy. This blow was repeated 150 times per minute. Undoubtedly all of the energy expended in the blow was not absorbed by the specimen, some being absorbed by the oak block and the loading mechanism. Before being subjected to this test, the average static pull-out strength was found to be 150 psi. After 50,000 cycles of impact loading, the static pull-out strength had decreased 17 per cent to 125 psi.

In 1909 Withey (4) reported the results of some repeated-loading tests of bond specimens made as a part of a general study of bond strength. Beam specimens were of 5-ft. span, 5 in. square at the ends and of smaller depth over two thirds of the span so that one reinforcing bar was exposed. The bar was thus surrounded by tension concrete. Concrete strengths at 28 days ranged from 1100 to 2300 psi. A load equal to 50 to 60 per cent of the static load could be repeated an indefinite number of times without failure to beams reinforced with plain bars, the higher values being found for rusted bars. For deformed bars this ratio was from 60 to 70 per cent. In these tests Withey found that pull-out specimens gave bond stresses as much as two times those found from beams.

A summary of some preliminary repeated-loading experiments made prior to a proposed extensive investigation were given by Kirsch (**5**) in 1909. Clean and rusty bars were embedded in portland and slag cement concretes of 1840 and 1000 psi., 28-day compressive strengths, respectively. Pull-out specimens were subjected to as many as 50 repeated loads equal to 12 per cent of the static pull-out load for portland-cement concrete and 22 per cent for slag-cement concrete. When tested to failure no reduction in the pull-out load due to the previous application of repeated load was observed. The data presented, however, show considerable variation and actually show a reduction in one case and an increase in another.

In 1922 Clemmer (**6**) reported the results of tests obtained with repeated load intended to simulate actual highway use. The results of this investigation were also summarized by Older (**7**) in 1924. Clemmer used unreinforced concrete beams, 6 in. square and 36 in. long, $1:2:3\frac{1}{2}$ mix by volume. Seven of these beams were tested simultaneously by arranging them as the spokes of a wheel radiating outward from a central hub. The space between the beams was filled with solid concrete, but the beams were about $\frac{1}{4}$ in. from this filler. Two pneumatic tires assembled on wheels and loaded with what was then a common wheel loading were rotated over these beams and passed over the mid-span 20 times each per minute. Thus, the actual application of load was at the rate of 40 cycles per minute. When loaded to the extent of 50 per cent of the static beam strength, no failure was encountered for one group of specimens after 1,130,976 cycles and no failure for another group after 5,000,000 cycles. When the tire size and wheel load was increased to 61 per cent of the static strength failure was obtained at cycles of from 16,782 to 199,836. The average number of cycles at failure was less than 50,000 and the average age of the concrete at failure was 174 days. Clemmer found the endurance limit of concrete beams was from 51 to 54 per cent of the static modulus of rupture.

Crepps (**8**) in 1923 reported on the fatigue strength of mortar as obtained from beam specimens. Unreinforced mortar beams of a 1:2 mix were cast 30 in. long and 4 by 4 in. in cross-section over the gage length of 10 in., and 4 by 6 in. in cross-section at the shouldered ends. The specimens were rigidly clamped at the base shouldered end and were loaded by a lever fixed to the upper shouldered end so that a constant bending moment and stress were produced along the entire gage length. Dead weights were used for load and were raised and lowered 10 times per minute onto the lever fixed to the specimen. The stresses in the specimen were checked by the use of a 10-in. Berry strain gage over the reduced portion. The endurance or fatigue limit was reached within 300,000 cycles and it was observed that beams cured for 28 days showed no definite endurance limit at loads equal to from 40 to 60 per cent of the static ultimate strength, beams cured for 4 months had an endurance limit at stresses of from 50 to 55 per cent of the static ultimate stress, and beams cured for 6 months showed an endurance limit at stresses of 55 per cent of the static ultimate stresses.

A short report of work in progress under the auspices of the Highway Research Board was given by Hatt (**9**) in 1924. This report found the endurance limit within an average of 20,000 cycles at a stress of from 50 to 55 per cent of the static ultimate for dry mixes and about 37 per cent for wet mixes. This was the first time any investigator had studied the water-cement ratio in connection with fatigue. Hatt also found that specimens cured for longer periods of time had higher endurance limits.

In 1929 Ewing (10) summarized some of this work in a brief article but presented no new material.

One of the most complete investigations of the effect of repeated loading on concrete and reinforced concrete was made at Karlsruhe Institute of Technology in Germany and was reported (in English) by Probst (11) before the Institution of Structural Engineers in London in 1931. This report covered work which had been in progress for ten years prior to that date. Investigation was made using portland-cement concrete with a cement factor of 0.206 cu. ft. of cement per cubic foot of concrete. The mix was proportional to 1:2.7:4.6 by volume and a water-cement ratio of 6 gal. per sack. Specimens were moist-cured for periods of from 7 to 12 months. Because of the limitations of the capacity of the repeated-loading machine, the size of the specimen was 2.76 by 2.76 in. in cross-section and 15.8 in. high. Loads were repeated at 60 cycles per minute. Alternation loadings were chosen which caused lower stress limits of 114 psi. and upper stress limits of 707, 794, and 1142 psi. These were approximately 30, 38, and 47 per cent of the ultimate static pull-out loads at rupture of similar specimens of the same age.

Additional tests were also made to study the formation of fissures in reinforced-concrete beams under repeated bending, and their influence on the load capacity. Specimens were cast as rectangular beams, reinforced and nonreinforced, with a cross-section 6 by 10 in. and a span of 6 ft. They were loaded symmetrically by two concentrated loads about 2 ft. apart. The beams were designed in such a way that failure would depend upon the yield point of the longitudinal bars. Load applications were repeated 90 times per minute.

Probst found that for compression-type specimens the endurance limit was from 47 to 60 per cent of the ultimate static strength. A slight strengthening was observed for repeated loads less than this value. Observed permanent deformation was found to diminish after temporary cessations of loading. Reinforced beam specimens showed an endurance limit of 50 per cent of the static strength. The load or number of cycles at which fissures were developed was considered the criterion for failure in the beam tests.

Cassie (12) in 1939 reported on the results obtained with beams 6 months old, loaded at any selected speed between 20 to 100 cycles per minute. He also observed that the permanent deformations increase relative to the elastic deformations, and that such deformations are greater in young than in old concrete. While the deformation of old concrete is mostly elastic, this condition may be reached with young concrete by preloading. Greater deformations were observed for the specimens tested at 20 cycles per minute than for those tested at faster speeds. Most of the observed cracks reached a constant value of width after a period of load repetition. Cassie also found that the endurance limit of concrete was about 50 per cent of the static compressive strength.

In 1940, Lea (13) reported to the Institution of Structural Engineers in London on the results of an investigation that included measurements of the strain in three test beams before and after repeated loadings. The strain measurements showed that the apparent modulus ratio of concrete beams depends on the number of repetitions of the load and on movements such as creep, and that it varies in beams as nearly alike as it is possible to obtain in careful laboratory preparation. From the results of repeated-loading tests on seven reinforced-concrete beams which were subjected to as many as 11,000,000 repetitions, it was found that the lowest load at which the beam will ultimately fail under repeated loading is about 70 per cent of the static breaking strength.

Lea also gave an account of a few tests made to determine the effect of repeated loading on the bond strength between concrete and steel. Specimens consisted of $\frac{1}{2}$-in. plain rods embedded to a depth of 3 in. in a cylinder 3 in. in diameter, and made of a 1:3 cement-sand mortar. These specimens were tested at 2000 cycles per minute for 14 days in a Haigh type of fatigue-testing machine. One series of specimens was subjected to repeated stresses varying from zero to a maximum, and a second series was subjected to stresses varying from one value in tension to an equal value in compression. In the first series of tests, the lowest load at which the bond stress failed in fatigue was found to be about 300 psi., or about 50 per cent of the static bond stress. When the bond failed, the rod drew out of the mortar. The lowest range causing failure was the same for the second series of tests and the rod in this case also drew out at failure. These observations of Lea's would again seem to justify using a specimen where the concrete is in compression and the steel in tension.

Other investigators, including Watstein (**14**), have shown that the bond stresses are not uniformly distributed along the bar, but are very high at the loaded end and gradually taper out to zero at the unloaded end. The average bond strength, therefore, does not represent the maximum unit bond stress present in the test specimen. Failure in bond occurs at the loaded end first and progresses toward the unloaded end.

In the light of previous work it would appear that to subject bond specimens of the pull-out type to varying cycles of load and then loading them to failure in the ordinary pull-out test, would make it possible to determine an S-N curve (average static bond stress after repeated loading *versus* cycles of loading) for bond strength. While not as satisfactory as a method which would permit failure of the specimen due to repeated load only, it was considered to be the most likely first step. The general pattern and trend of the data could be determined, and the worth of further investigation, involving further variables, would be apparent.

TABLE I.—PROPERTIES OF CEMENT.

Normal consistency, per cent[a]	27.0
Vicat setting time, hr.[a]:	
Initial	2.35
Final	4.45
Tensile strength, 7 days, psi.[a]	440.0
Autoclave expansion, per cent[b]	0.13
Specific surface, sq. cm. per g.[c]	1800.0

[a] Standard Specifications for Portland Cement (C 150-44), 1944 Book of A.S.T.M. Standards, Part II, p. 1.

[b] Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 - 43), *Ibid.*, p. 44.

[c] Standard Method of Test for Fineness of Portland Cement by the Turbidimeter (C 115 - 42), *Ibid.*, p. 47.

Because of this concept of the scope of the work, investigation for the design of the testing machine necessitated a device that could readily be adapted to various types of specimens or to increased loads. It appeared reasonable that the water-cement ratio and types of aggregates be maintained constant.

MATERIALS AND TEST SPECIMENS

Cement and Aggregates Used in Concrete:

A standard type of portland cement having the physical properties given in Table I was used. The cement was carefully stored in large galvanized cans to prevent segregation and moisture changes.

The Allegheny River sand and gravel used for the fine and coarse aggregates

TABLE II.—GRADINGS AND PROPERTIES OF SAND AND GRAVEL.

GRADINGS			
Allegheny River Sand		Allegheny River Gravel	
Sieve Size	Percentage Passing	Sieve Size	Percentage Passing
No. 4	100	1½ in.	100
No. 8	98	1 in.	96
No. 16	77	¾ in.	74
No. 30	42	½ in.	35
No. 50	15	⅜ in.	11
No. 100	2	No. 4	3

PHYSICAL PROPERTIES	Allegheny River Sand	Allegheny River Gravel
Unit weight, per cu. ft.[a]	101	108
Percentage voids[b]	35	38
Apparent specific gravity[c]	2.50	2.80
Fineness modulus[d]	2.66	7.81

[a] Standard Method of Test for Unit Weight of Aggregate (C 29 – 42), 1944 Book of A.S.T.M. Standards, Part II, p. 449.

[b] Standard Method of Test for Voids in Aggregate for Concrete (C 30 – 7), *Ibid.*, p. 451.

[c] Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate (C 128 – 42), *Ibid.*, p. 445.
Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 – 42), *Ibid.*, p. 443.

[d] Standard Specifications for Concrete Aggregates (C 33 – 44), *Ibid.*, p. 423.

had the gradings given in Table II. The other physical properties given in Table II were determined for the sand and gravel in accordance with the appropriate A.S.T.M. procedures indicated.

The concrete mix was proportioned in the ratio of 1:1.5:3.0 by volume and employed a water-cement ratio of 7.5 gal. per sack. This mix was designed to produce a 28-day compressive strength of 3000 psi. This particular strength was selected as a maximum in order to stay within the capacity of the repeated-loading machine. The quantity of material necessary to make six specimens plus three compression-test cylinders was determined by the absolute-volume method, and all subsequent proportioning of materials was then made on the basis of weight. The average slump of the mix was 8 in.

Test Specimens:

Six test specimens were cast at one

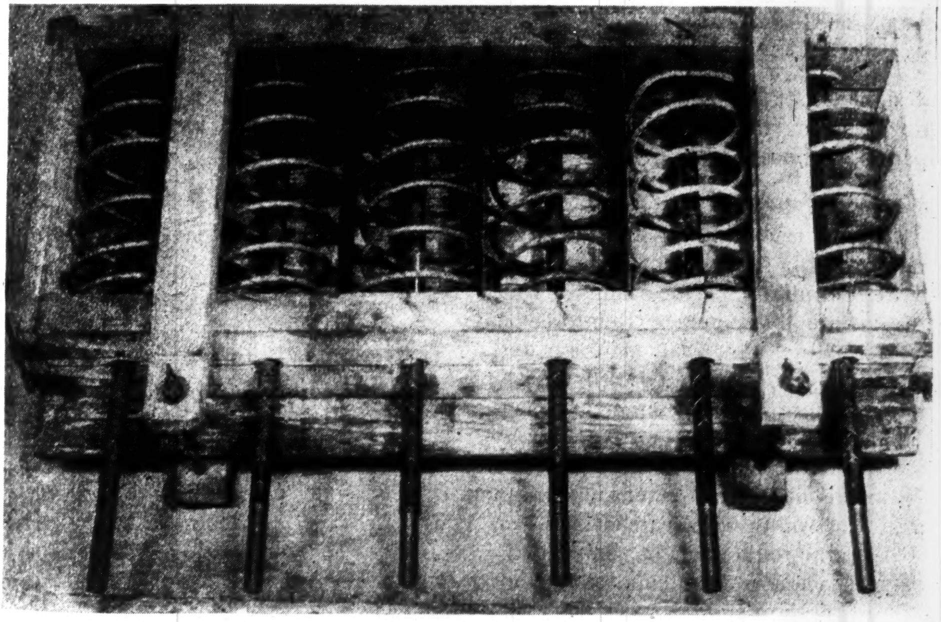

FIG. 1.—Collapsible Mold.

time to provide uniformity and duplication of test results. The mold is shown in Fig. 1. The over-all dimension of each specimen was 5 in. wide by 5 in. deep with a length varying from 5 to 10 in. Steel plates, $\frac{1}{16}$ in. thick, were used as separators between adjoining specimens. The inside of the mold and the steel plates were coated with oil prior to casting the specimens which were left in the mold for an initial moist-curing period of 3 days. They were then cured at room temperature and humidity for a period of 25 days. All specimens were cast with the bars in a horizontal plane, and the concrete was thoroughly worked around the test bar with a vibrator. The mold was so designed that it could easily be broken down after the 3-day initial curing period without harming the specimens.

TABLE III.—PHYSICAL PROPERTIES OF REINFORCING-BAR STEEL.

(Values Represent the Average of Three Tests)

Proportional elastic limit, psi.[a]	39 800
Yield point (determined by drop of beam), psi.[a]	46 310
Tensile strength, psi.[a]	81 450
Modulus of elasticity, psi.[b]	30 450 000
Elongation in 8 in., per cent	21.4
Reduction of area, per cent	32.7

[a] In accordance with Standard Methods of Tension Testing of Metallic Materials (E 8 – 42), 1944 Book of A.S.T.M. Standards, Part I, p. 962.

[b] Obtained with an Olsen 2-in. averaging extensometer, having a least reading of 0.0001 in.

Steel Reinforcing-Bar Material:

A $\frac{5}{8}$-in. round intermediate grade of reinforcing-bar steel, conforming to A.S.T.M. Standard Specifications for Billet-Steel Bars for Concrete Reinforcement (A 15 – 39),[5] was used in these tests. This bar was of the deformed type and had a pattern known commercially as the "diamond" pattern. The average physical properties given in Table III were obtained based on extensometer tension tests of three specimens.

A spiral reinforcement, embedded in each specimen to prevent a splitting failure of the concrete, was made from a $\frac{1}{4}$-in. bar of the same type of steel as the $\frac{5}{8}$-in. round. A 4-in. coil was made by wrapping the $\frac{1}{4}$-in. bar around a mandrel. This gave a pitch of about $1\frac{1}{4}$ in. to the turns and provided satisfactory reinforcement. The bars were embedded in the concrete by placing them in the mold and inside the spiral reinforcement as shown in Fig. 1. They were used as received with the hot-rolled mill scale in place, but with no rust or loose scale present. Each bar was allowed to project 2 in. beyond the unloaded end of the specimen in order to measure the slip at this point. At the loaded end of the specimen, the bar projected 10 in. and was threaded with a $\frac{5}{8}$-in. U. S. Standard thread to permit the loading knuckle to be attached. The following bond areas and ratios of embedment length L to bar diameter d were obtained for the length of specimen shown:

Specimen Length, in.	Bond Area, sq. in.[a]	L/d
10.00	19.63	16.0
8.00	15.72	12.8
6.25	12.28	10.0
5.00	9.87	8.0

[a] Area of $\frac{5}{8}$-in. round bar, neglecting projections = 0.307 sq. in.

TESTING EQUIPMENT

Concrete Test Cylinders:

Compressive strength of the concrete test cylinders was obtained in an Olsen 150,000-lb. capacity Universal testing machine. Both the method of making and the method of testing the cylinders conformed with A.S.T.M. Tentative Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 – 44 T)[6] and Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (C 39 – 44).[7]

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[5] 1944 Book of A.S.T.M. Standards, Part I, p. 102.

[6] 1944 Book of A.S.T.M. Standards, Part II, p. 1344.

[7] *Ibid*, p. 470.

Slip Measurement:

Pull-out tests were made with the specimen supported on a ½-in. thick steel plate resting on the fixed head of a 50,000-lb. capacity Olsen testing machine, as shown in Fig. 2. The loaded end of the specimen was plaster-grouted at the point of contact with the steel plate and was placed in a true vertical position with the aid of a level. The projecting end of the bar was held in V-notch grips in the testing machine.

A Federal dial, supported on a three-legged stand, was mounted on the unloaded end of the specimen so that the end of the dial stem engaged the flat end of the bar. This dial, which read directly to 0.001 in. and by estimation to 0.0001 in., was used to measure the slip of the unloaded end of the bar. Load was applied in increments of 4000 lb. to a total of 12,000 lb., and then in increments of 2000 lb. until the bar pulled out of the concrete and bond failure was complete.

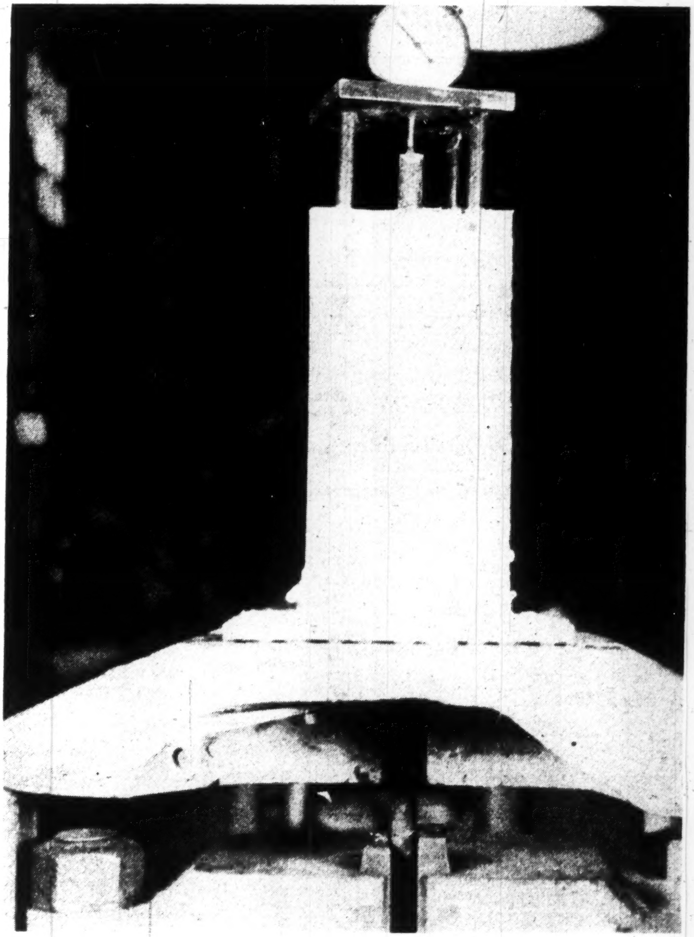

FIG. 2.—Specimen Set-up for Pull-out Test.

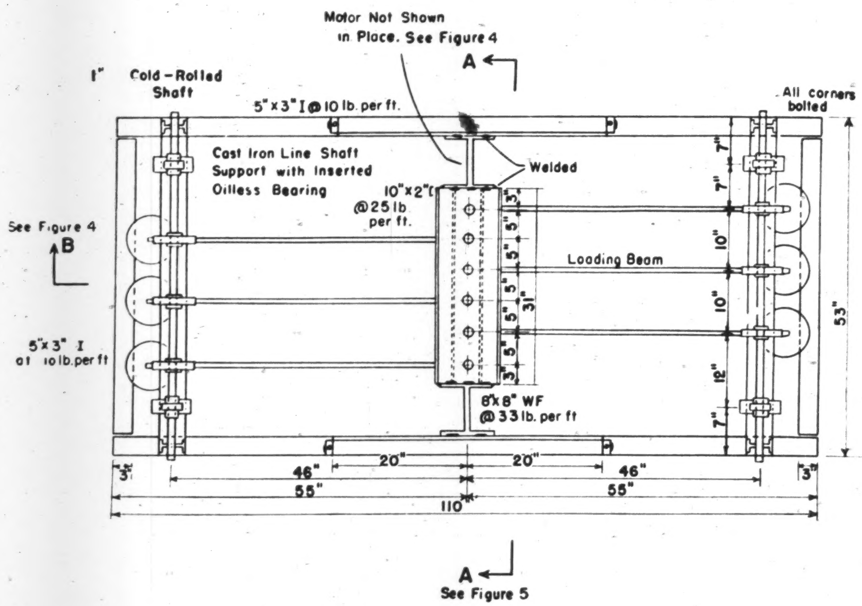
Motor Not Shown
in Place. See Figure 4
A
1" Cold-Rolled Shaft
5"x3" I @ 10 lb. per ft.
All corners bolted
Cast Iron Line Shaft Support with Inserted Oilless Bearing
Welded
10"x2" [@ 25 lb per ft.
See Figure 4
B
Loading Beam
B
5"x3" I at 10 lb. per ft
8"x8" WF @ 33 lb. per ft
7"
7"
10"
10"
12"
7"
3"
5"
5"
5"
5"
5"
3"
31"
53"
3"
46"
20"
20"
46"
3"
55"
55"
110"
A
See Figure 5

FIG. 3.—Details of Repeated-Loading Machine.

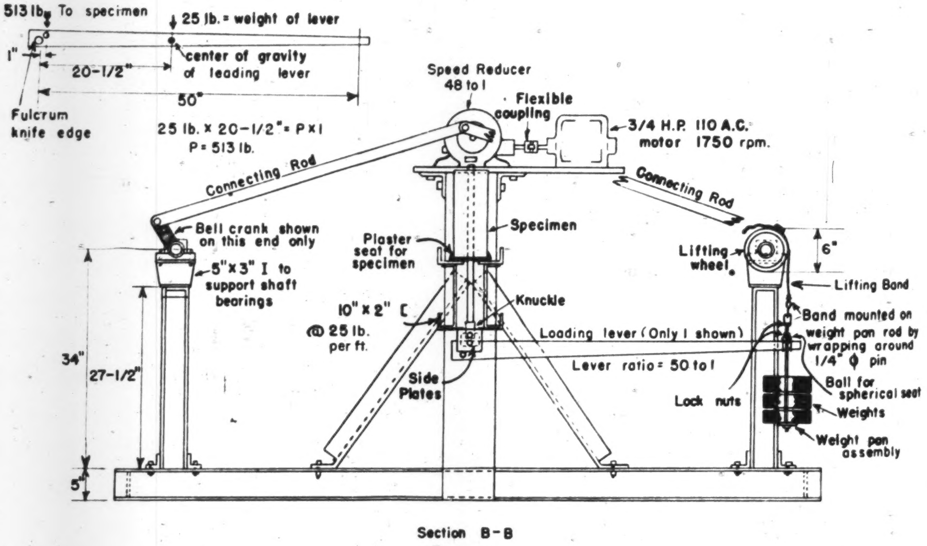
513 lb. To specimen
25 lb. = weight of lever
1"
20-1/2"
center of gravity of loading lever
50"
Fulcrum knife edge
25 lb. x 20-1/2" = P x 1
P = 513 lb.
Speed Reducer 48 to 1
Flexible coupling
3/4 H.P. 110 A.C. motor 1750 rpm.
Connecting Rod
Connecting Rod
Bell crank shown on this end only
5"x3" I to support shaft bearings
Plaster seat for specimen
Specimen
Lifting wheel
6"
Lifting Band
Knuckle
Band mounted on weight pan rod by wrapping around 1/4" ϕ pin
10" x 2" [@ 25 lb. per ft.
Loading lever (Only 1 shown)
Lever ratio = 50 to 1
Ball for spherical seat
Side Plates
Lock nuts
Weights
Weight pan assembly
34"
27-1/2"
5"
Section B-B
Figure 3

FIG. 4.—Details of Repeated-Loading Machine.

Repeated-Loading Machine:

The repeated-loading machine employed in this investigation was designed to permit a variation in the magnitude of load and type of test specimen, being adaptable to the pull-out type of specimen or to beams tested transversely. A feature of the machine is the use of dead load with which to apply load to the bars, rather than mechanical application of load. This feature minimizes the effects of vibration and the possibility of error. Figures 3, 4, and 5 show the details of the repeated-loading machine. The complete apparatus is shown in Fig. 7. Two WF-beams serve as upright supports. Between these sections is a 12-in. channel on which the specimens rest. Immediately beneath this horizontal channel are two vertical 12-in. channels which are also welded between the WF-beams and which support the horizontal channel as shown in Figs. 4, 5, and 7. These sections are employed to produce a rigid support which will not deflect appreciably transversely when load is applied to the test specimens.

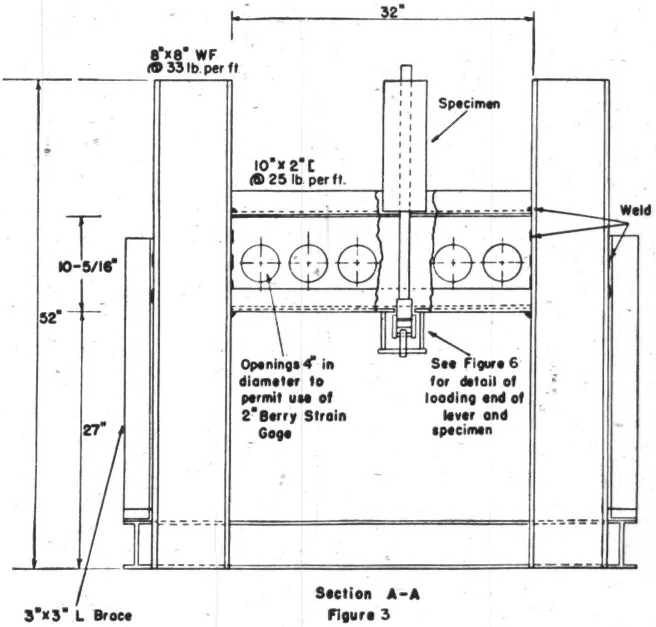
32"
8"x8" WF
@ 33 lb. per ft.
Specimen
10"x 2" [
@ 25 lb. per ft.
Weld
10-5/16"
52"
27"
Openings 4" in diameter to permit use of 2" Berry Strain Gage
See Figure 6 for detail of loading end of lever and specimen
Section A-A
Figure 3
3"x3" L Brace

Fig. 5.—Details of Repeated-Loading Machine.

Holes $1\frac{1}{8}$ in. in diameter are drilled along the horizontal supporting channel to permit the specimens to be placed in a vertical position with the loaded end of the reinforcing bars projecting through it so that a reinforcing bar 1 in. in diameter may be tested. The two vertical 12-in. channels have one hole, 4 in. in diameter, along the center line of each reinforcing bar. These holes are shown in Fig. 5 and permit a 2-in. Berry strain gage to be mounted on each side of the reinforcing bar in order to check the actual load on the specimen. This entire center section which supports the specimens is rigidly fastened and braced to two 5-in. I-beams, each of which is 110 in. long as shown in Figs. 3 and 4. The length of the 5-in. I-beams is such that they extend beyond the ends of the loading levers and, consequently, prevent tipping of the central specimen support. Across the ends of the 5-in. I-beams, another length of 5-in. I-beam is used as a connection to provide resistance to horizontal spread. When the machine was set up, the entire frame was raised from the floor, carefully leveled both vertically and horizontally, and then grouted in place with a cement-sand mortar.

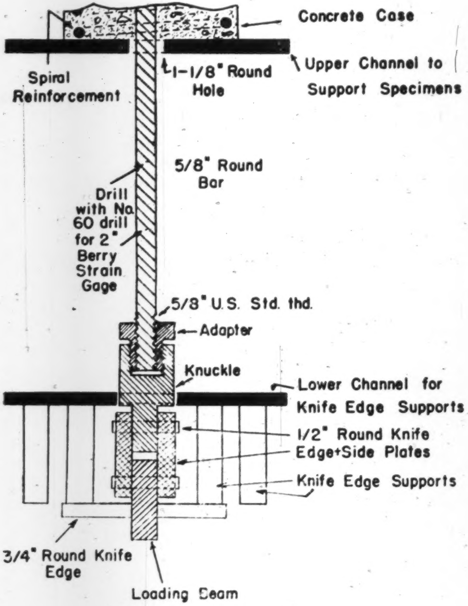
Concrete Case
Spiral Reinforcement
1-1/8" Round Hole
Upper Channel to Support Specimens
5/8" Round Bar
Drill with No. 60 drill for 2" Berry Strain Gage
5/8" U.S. Std. thd.
Adapter
Knuckle
Lower Channel for Knife Edge Supports
1/2" Round Knife Edge+Side Plates
Knife Edge Supports
3/4" Round Knife Edge
Loading Beam

FIG. 6.—Details of Repeated-Loading Machine.

Figure 6 shows the details of the connection between the loading lever and the reinforcing-bar test specimen. Each test bar is threaded on the loaded end with a $\frac{5}{8}$-in. U. S. Standard thread. A knuckle is threaded onto this end of the reinforcing bar. The inside thread of the knuckle is long enough to permit vertical adjustment of the knuckle with respect to the position of the loading lever.

A $\frac{1}{2}$-in. diameter steel pin serving as a knife-edge (0.36 per cent carbon rod), 2 in. long, is permanently inserted in the knuckle in the position shown in Fig. 6, and the two steel side plates hang on this knife-edge. The loading lever, in which two round knife-edges (pins) are permanently attached, is placed between the side plates and against the steel knife-edge supports. With the fulcrum knife-edge pin bearing against its supports, the loaded end of the loading beam is lowered until both the fulcrum knife-edge pin and the loading knife-edge pins are bearing properly. If the loading lever is below the horizontal, it is again raised, the side links are removed, and the loading knuckle is given one-half turn. This equipment is then replaced and the loading lever again checked. This process is repeated until the loaded end of the loading lever is slightly higher than the fulcrum end when the lever is not supporting load.

When the loading lever is in place and adjusted horizontally, the scale-pan hanger shown in Fig. 4 is placed in position on the loaded end of the lever. A spherical adjusting nut at the top of the scale-pan hanger rod rests in a spherical seat in the loading lever as shown in Fig. 4. Weight in the desired amount is hung on the scale-pan. The added weight depresses the loading lever so that at the loaded end it is about the same angle below the horizontal as it previously was above. The lifting belt is then attached to the upper end of the scale-pan hanger rod. This lifting belt is carried upward and over the lifting wheel. With the load hanging on the loading rod, this lifting belt is locked in position to the lifting wheel so that a slight amount of buckle is obtained in the lifting belt. This indicates that all the load is on the loading rod. Figure 8 shows the detail of the lifting wheel and lifting bands.

The mechanism which is used to apply and release the load is shown in Figs. 4 and 7. Power is obtained from a $\frac{3}{4}$-hp., 110 a-c. motor, operating at 1750 rpm., and controlled by a variable-speed starting box, as shown. A Westinghouse Motor-Watchman guards against overload. The motor is connected by a flexible coupling to a Boston speed reducer having a reduction factor of 48:1. A flat-faced wheel is mounted on the output shaft of the speed reducer. This wheel has three holes placed at 1½, 2, and 2½ in. from the center of rotation. A connecting rod connects this wheel to a crank arm mounted on one of the lifting wheel shafts, as shown in Figs. 4 and 7. This crank arm has holes drilled along its length at distances of 2, 2½, 3, 3½, and 4 in. from the center of rotation. For ordinary complete removal of load, the connecting rod is mounted in the middle hole of the driving wheel and to the 4-in. hole on the crank arm. As the driving wheel revolves, the connecting rod is moved with a horizontal component which throws the crank arm through approximately 90 deg. of rotation. The crank arm, which is fastened to the shaft supporting the load-lifting wheels, causes the load-lifting straps to wind onto the lifting wheel in one direction and remove the load from the loading lever and then to unwind from the lifting wheel, thus applying load to the loading lever. When the three load-lifting wheels on one end of the machine are raising the load off the loading levers at the end, the load-lifting wheels at the other end of the machine are applying the load to the loading levers. This is a desirable feature, since it eliminates any possibility of peak loads on the driving motor. About 36.4 cycles of loading and unloading are obtained in 1 min. This speed produces a little more than 52,000

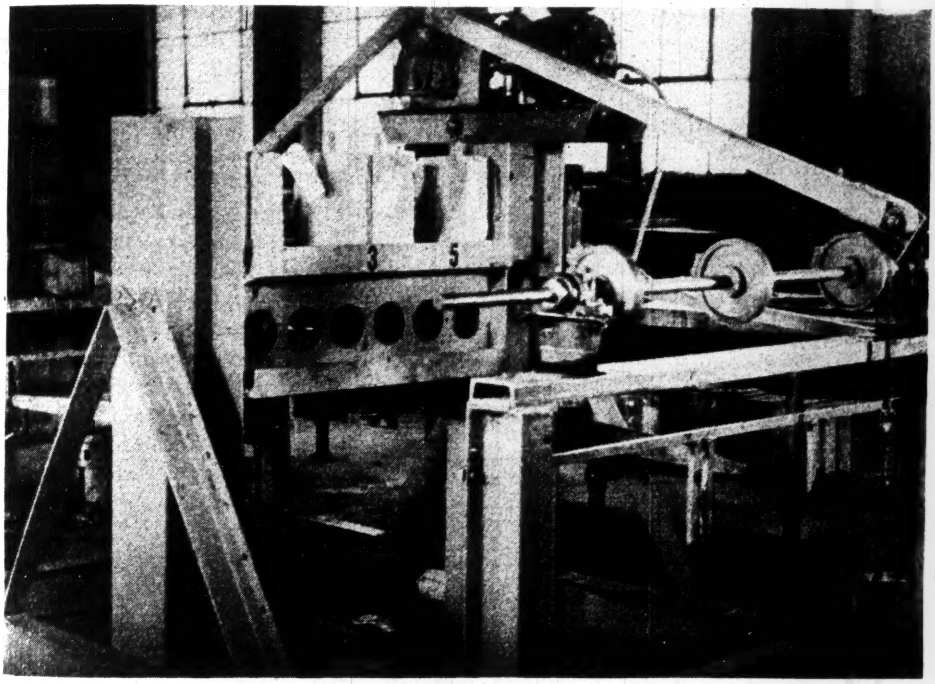

FIG. 7.—Completed Repeated-Loading Machine with Specimens in Place.

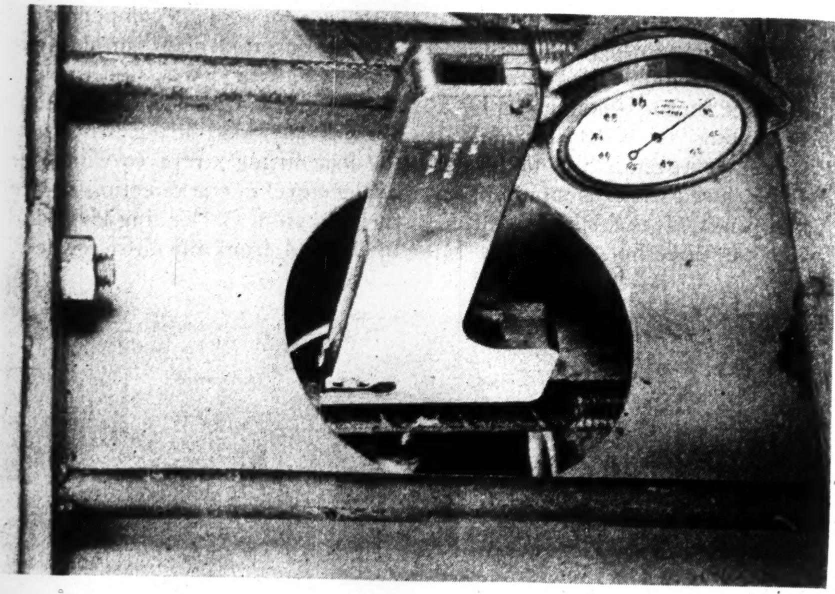

FIG. 9.—Checking Load on Bar with Strain Gage.

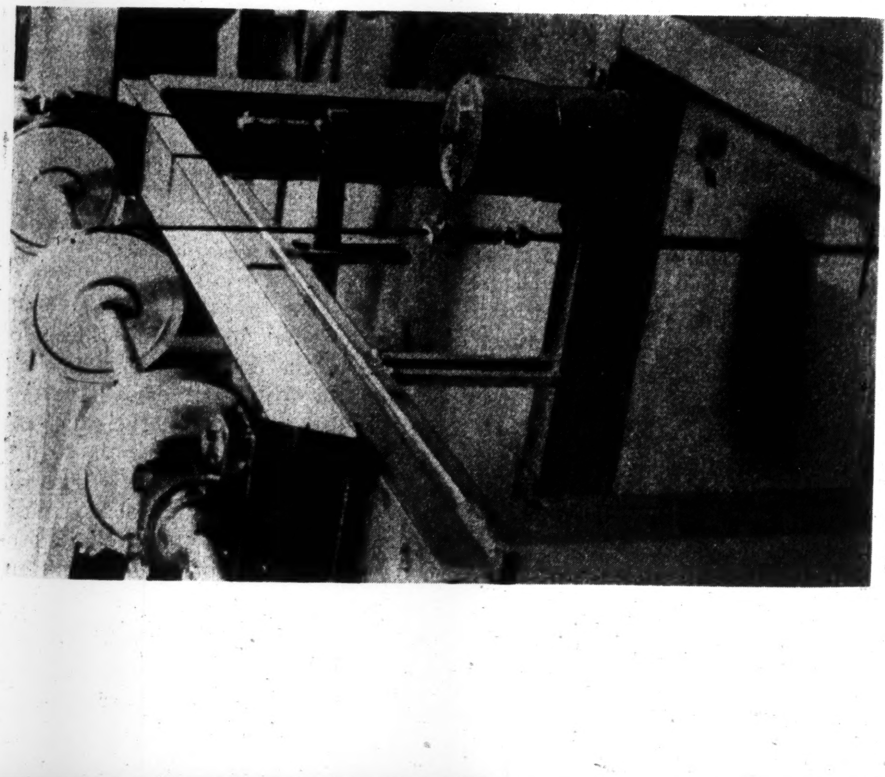

FIG. 8.—Close-up of Lifting Wheels, Bands, and Clamps.

repetitions per 24 hr. and requires about 19 days to reach one million cycles. A speed counter is attached to the output shaft of the speed reducer to measure the number of cycles applied to the specimens.

As shown in Fig. 4, the specimens rest on plaster seats on the supporting channel. They are placed on this seat after the plaster has started to harden and are made vertical with the aid of a lever. The $\frac{1}{16}$-in. separators used in molding the specimens, provide enough space between them as they rest on the supporting channel so that they do not touch.

The load applied to the specimen is equal to the dead load of the loading lever plus the applied load. Figure 4 shows the manner of calculating the dead load based on the weight of the lever and the distance from the fulcrum knife-edge to the center of gravity. This latter distance was obtained by balancing the lever on a $\frac{1}{2}$-in. diameter rod and then measuring the distance from the balance point to the fulcrum used in the repeated-loading machine. As is indicated in Fig. 4, the dead load thus applied is 513 lb. This load is always applied to the specimen, since the loading lever is not lifted by the lifting device. The load applied to the specimen by the dead weights is equal to the sum of the weights plus the 2-lb. weight of the scale pan, this entire amount being multiplied by the lever ratio of 50. Thus, if the load on the scale pan is 98 lb., the following loads would be applied to the specimen:

minimum load = 513 lb.
maximum load = $(98 + 2)\,50 + 513$
$= 5513$ lb.

The maximum weight which the scale pan can hold is governed by the fulcrum knife-edge and is about 165 lb. This weight produces a load of about 8760 lb., or 50 per cent of the static pull-out strength of a 5-in. specimen.

In order to calibrate the load on each specimen, use is made of the Berry strain gage set up for a 2-in. gage length, as shown in Fig. 9. The loading lever is placed on the specimen, the gage is fixed by a clamp into the previously drilled gage holes shown in Fig. 6, and a zero reading taken. Weights are placed on the scale pan and the strain gage again read. The difference between the zero and final readings is recorded. This procedure is repeated on the other side of the bar, and the difference again obtained. The stress in the rod may easily be found from the average difference and the modulus of elasticity. The weights on each loading lever are adjusted until the load on the specimen is the same for all the specimens in the series being tested.

Test Procedure:

When the specimens were removed from the mold, they were numbered from 1 through 6 beginning with the block on the left-hand side of the mold, as viewed in Fig. 1. Specimens Nos. 1 and 6 were used for static pull-out tests and the other four were placed in the repeated-loading machine. All levers were attached to the reinforcing rods, but only specimen No. 2 had its lifting band attached and the correct weights applied. The procedure for testing was then as follows:

1. Begin application of load to specimen No. 2 only and continue for 250,000 cycles (for example).
2. After specimen No. 2 has reached 250,000 cycles, apply weights to specimen No. 3, attach lifting bands, and begin application of load.
3. After specimen No. 2 has reached 500,000 cycles, attach weights to specimen No. 4, etc., and begin application of load.

Test two concrete cylinders for compressive strength.

Test specimen No. 1 for static pull-out strength, measuring slip.

4. After specimen No. 2 has reached 750,000 cycles, apply weights to specimen No. 5, etc., and begin application of load.

5. (*a*) After specimen No. 2 has reached 1,000,000 cycles (for example), remove all specimens from the testing machine and obtain the static pull-out strength, measuring slip.

(*b*) Test third concrete cylinder for compressive strength. Obtain average compressive strength by averaging strength of this specimen with specimens previously tested.

(*c*) Test specimen No. 6 for static pull-out strength, measuring slip. Obtain average "pilot" static pull-out strength by averaging this specimen with specimen No. 1.

The cycles of loading applied to each specimen were then as follows, (for example):

Specimen No. 2 = 1 000 000
Specimen No. 3 = 750 000
Specimen No. 4 = 500 000
Specimen No. 5 = 250 000

In test step No. 1 above, the number of cycles between the start and end of the tests could, of course, be varied. The total number of cycles applied to each specimen was varied as indicated in test step No. 5 by stopping at a maximum of 1,000,000 cycles, or continuing to some other maximum, such as 4,000,000 cycles. In this latter case the additional cycles were added to each specimen. Two sets of specimens were made for each test run and the above procedure was repeated for each set. In some cases the number of cycles was varied indiscriminately without regular increment values.

TEST RESULTS AND DISCUSSION

Repeated-Loading Machine:

The repeated-loading machine was completed in November, 1941, and has been in almost constant use since that time. Operation has been entirely satisfactory and only two minor failures of the machine occurred due to repeated loading. In both cases failure was due entirely to defects found in the steel. One such failure occurred in a knife-edge and the other in a loading lever adjusting knuckle. During operation, the frame has been observed to be very rigid.

The machine appears to be adequately powered and lifts the weights without heating, even under maximum load application to all specimens. The speed reducer must be checked for oil once every two weeks.

Measured loads determined from stresses in the loaded end of the reinforcing bar have been found to agree within 2 per cent with values calculated from the applied load and the lever ratio as given in Fig. 5, whether the load is statically applied or the machine is in operation. Stresses were checked while the machine was in operation by observing the maximum value to which the hand of the strain gage dial moved. This could be done since the load was slowly applied and removed. The slow speed of loading also accounts for the fact that the calculated and measured loads were in such good agreement. It is felt that the speed of the machine could be doubled without introducing inertia effects.

The maximum load of 165 lb. that can be applied to the scale pan produces a force equal to 50 per cent of the static pull-out strength of a 5-in. specimen. In the review of previous work, it was found that the fatigue strength of concrete is approximately 55 to 60 per cent of the static compressive strength. The maximum repeated pull-out value of 50 per cent of the static pull-out load would thus seem to be low if failure was to be encountered as a result of repetitions of load only, rather than by static pull-out following repetition of load. If this was to be done with the machine described herein, the embedment length would have to be made less or a smaller diameter bar used. Either of these would decrease the static pull-out load, the length approximately as the first power of the shortening and the diameter approximately as the ratio of the squares of the diameters. As the diameter and cross-sectional area are reduced, the unit-stress *in the bar* at the pull-out bond stress becomes higher. Because the diameter at the root of the thread governs, a specimen diameter less than $\frac{5}{8}$ in. causes a stress that is dangerously near the proportional-elastic limit of the steel. When coupled with repeated loading, this high stress is likely to cause failure of the bar rather than failure of bond. In the series of tests conducted, several bars did fail due to this condition.

The only way failure of this bar could be avoided would be to increase the capacity of the machine by making the knife-edges of a steel having a higher endurance limit. A load of 10,500 lb. on the specimen is equal to about 60 per cent of the static pull-out of a 5-in. specimen. This specimen load would require a lever load of 210 lb.

The author feels that the 5-in. specimen length should be considered a minimum. Embedment lengths less than 5 in. would be too sensitive to any defects or scale on the surface of the bar and might be expected to show considerable variation between comparative specimens.

Static Pull-Out Tests:

Characteristic stress-slip diagrams for static load are given in Fig. 10. The values presented represent the average of two specimens and are comparable with those given by Gilkey, Chamberlin, and Beal (**1**) for cleaned bars. The maximum variation of any one value from these average curves was 6 per cent. The fact that the apparent unit bond stress increases with decreased specimen length has been shown by many investigators. This is due to the tendency of the bond stress to be very high at the loaded end of the embedded bar, as has been shown by Watstein (**14**). Watstein has shown that the maximum unit stress may be as much as three times the average unit stresses. Due to the wide variation between minimum and maximum stresses at the unloaded and loaded ends of the 5-in. specimen, it might be expected that this size would be most severely influenced by repeated loading. This fact is borne out by the experimental results.

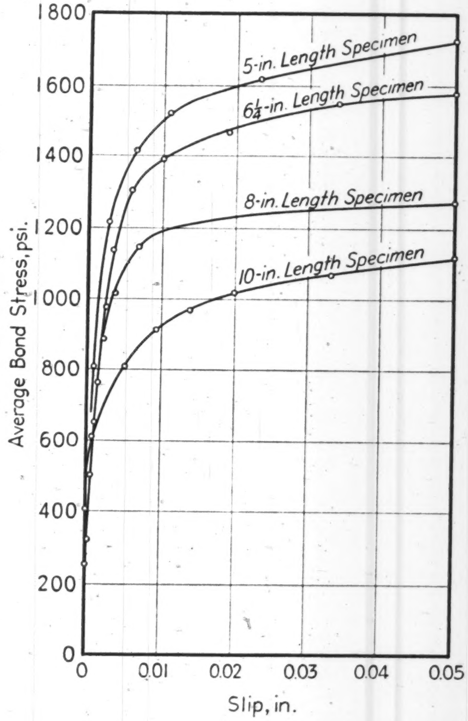

FIG. 10.—Stress-Slip Diagrams for Static Load.

Static Pull-Out Tests After Repeated Loading:

The effect of repeated loading on the stress-slip relationship is shown in Figs. 11, 12, 13, and 14 for the 10, 8, 6¼, and 5-in. specimens, respectively. Some of these data are compiled in Table IV. That the repeated loading has reduced the average unit bond stress at which slip occurs is obvious from these figures. For each of the specimens, about 4,400,000 cycles of load were applied. The percentage of static pull-out load that was repeated for this many cycles varied from 23.2 to 37.2 per cent, as may be seen from Table IV.

To determine the effect of repetitions of load on the stress-slip relationship for various specimen lengths, the following information was obtained from Figs. 11 to 14 and from Table IV for 0.01-in. slip:

Specimen	Static Pull-out Load on Specimen, per cent	Stress at 0.01-in. Slip		Reduction, per cent
		Static Load Only	After Load Was Repeated	
10-in.	23.2	920	825	10.5
8-in.	23.6	1200	1090	9.2
6¼-in.	33.5	1400	1115	20.4
5-in.	37.2	1510	1045	30.7

Although the amount of load applied to every specimen was not the same, nevertheless the data indicate that the 5-in. length was influenced more by repetitions of load than any of the other specimens. For this reason, all other tests were restricted to the 5-in. specimen length.

A slip of 0.01 in. is usually not considered as "first slip," a value of 0.0001

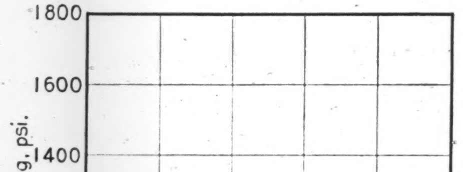

FIG. 11.—Effect of Repeated Loading on the Stress-Slip Relationship for 10-in. Specimens.

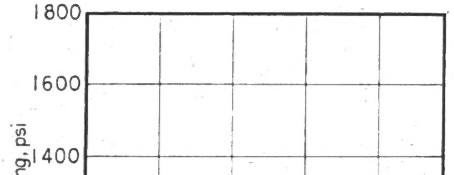

FIG. 12.—Effect of Repeated Loading on the Stress-Slip Relationship for 8-in. Specimens.

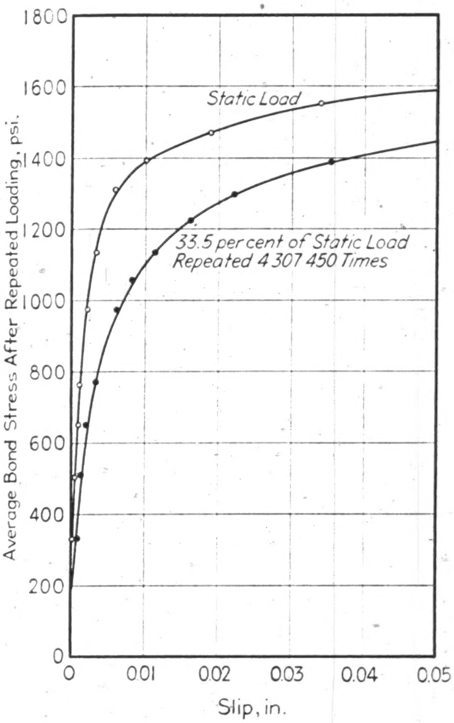

FIG. 13.—Effect of Repeated Loading on the Stress-Slip Relationship for 6¼-in. Specimens.

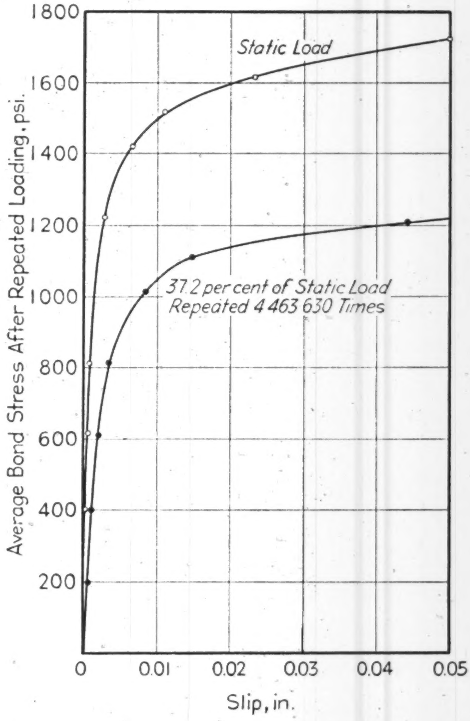

FIG. 14.—Effect of Repeated Loading on the Stress-Slip Relationship for 5-in. Specimens.

TABLE IV.—PULL-OUT LOADS AND STRESSES FOR VARIOUS CYCLES OF LOADING—VARIOUS LENGTHS.

Cycles and corresponding stresses represent the average of 2 specimens; pilot specimen stresses the average of 4 specimens; and compressive strengths the average of 6 specimens.

Specimen	Cycles	Ratio, R.B.L.[a] / S.B.L.	Maximum Pull-out Load, lb.	Maximum Pull-out Stress, psi.	Stress at 0.01-in. Slip	Stress at 0.05-in. Slip	Ratio, Max. B.S.[a] / Max. s_c	28-day s_c, psi.[a]
10-in.	Pilot	....	22 100	1125	920	1120	36.6	3080
	909 600	23.2	19 700[b]	1000[b]	662	790	32.5	
	2 048 480	23.2	21 530	1100	920	1080	35.7	
	2 992 560	23.2	21 300	1080	815	942	35.1	
	4 270 800	23.2	18 550	945	825	960	30.7	
8-in.	Pilot	....	21 250	1350	1200	1270	44.4	3045
	1 500 760	23.6	19 900	1270	1080	1070	41.7	
	2 000 080	23.6	20 000	1270	1150	1270	41.7	
	2 614 870	23.6	19 700	1250	1240	1250	41.0	
	4 600 100	23.6	17 700	1130	1090	1110	37.1	
6¼-in.	Pilot	....	19 440	1580	1396	1580	51.0	3095
	836 360	33.5	19 500	1590	1350	1580	51.4	
	3 834 000	33.5	18 400	1500	1260	1500	48.5	
	4 307 450	33.5	17 600	1430	1140	1400	46.2	
	5 325 000	33.5	16 900	1380	1150	1450	44.6	
5-in.	Pilot	....	17 500	1770	1510	1720	57.0	3110
	1 120 760	37.2	17 000	1720	1220	1520	55.3	
	1 488 010	37.2	Specimens mishandled					
	2 160 930	37.2	16 500	1670	1040	1270	53.7	
	4 463 630	37.2	15 400	1560	1040	1220	50.1	

[a] R.B.L. = repeated bond load; S.B.L. = static bond load; B.S. = bond stress; s_c = compressive strength.

[b] The two values giving this average were 22,240 and 17,160 lb. for load, and 1130 and 870 for stress. The first stress value has been assumed to be correct and the second value has been ignored in plotting.

in. being a more commonly used criterion. In these tests, no attempt was made to determine slips as small as this, a 0.001-in. dial being used. Figures 11 to 14 were used to determine the following stresses at 0.001-in. slip.

Specimen	Static Pull-out Load on Specimen, per cent	Stress at 0.001-in. Slip		Reduction, per cent
		Static Load Only	After Load Was Repeated	
10-in.	23.2	638	580	9.0
8-in.	23.6	650	650	0.0
6¼-in.	33.5	780	500	36.0
5-in.	37.2	880	390	55.7

Whether or not the stress at 0.0001-in. slip would be influenced to such a great extent as indicated by this table is not known. It is considered, however, that these data indicate some reduction must be expected.

Effect of Repeated Loading on Bond Stress:

In Fig. 15 are given stress-cycle diagrams for the 10, 8, 6¼, and 5-in. specimens subjected to repeated loads equal to 23.2, 23.6, 33.5, and 37.2 per cent, respectively, of the static pull-out stress. Although the curves are not parallel, they have the general characteristics of "fatigue" or repeated-load diagrams in that an increase in repetitions causes a decrease in the average bond stress.

The data for Figs. 11 to 14 are compiled with other data in Table IV. From this table it may be seen that the stress at 0.01 and at 0.05-in. slip also decreases generally with increased cycles of load. The data are erratic, however, and lead to no general conclusion. For this reason no slip measurements were made for subsequent tests on 5-in. specimens.

From Table IV the percentage that each bond stress is of the static unrepeated bond stress may be calculated. These are found to be 84.0, 83.8, 87.5, and 88.1 per cent for the 10, 8, 6¼, and 5-in. specimens, respectively. Such high percentages indicated that the repeated load being applied to the specimens was not great enough to affect appreciably the bond between the concrete and the steel. Because of this condition, several more test groups were prepared in the 5-in. specimen length, and the loads were varied above and below the 37.2 per cent of the static bond load which was applied to the 5-in. specimens reported in Fig. 15.

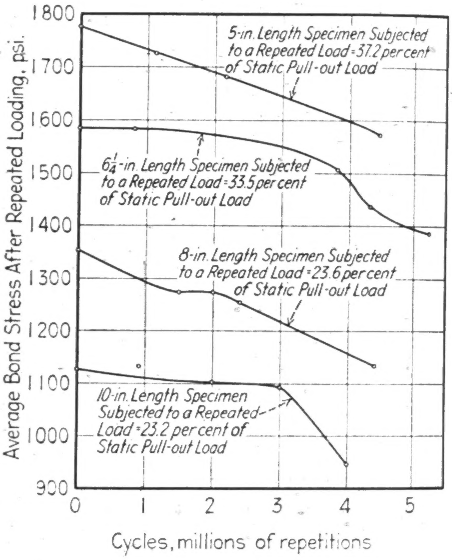

FIG. 15.—Stress-Cycle Diagrams for Specimens Subjected to Repeated Loads.

Figure 16 gives the stress-cycle diagrams for the three 5-in. length specimens tested. The maximum repeated load applied was 49.8 per cent of the static bond load and the minimum was 23.5 per cent. These data are summarized in Table V. As mentioned previously, load-slip determinations were not made for these additional 5-in. specimens. From Fig. 16, it is apparent that, as the repeated bond load is increased to near the 55 to 60 per cent value which other investigators have found for the

TABLE V.—PULL-OUT LOADS AND STRESSES FOR VARIOUS CYCLES OF LOADING—5-IN. LENGTH.

Cycles and corresponding stresses represent the average of 2 specimens; pilot specimen stresses, the average of 4 specimens; and compressive strengths the average of 6 specimens.

Cycles	Ratio, $\frac{\text{R.B.L.}^a}{\text{S.B.L.}}$	Maximum Pull-out Load, lb.	Maximum Pull-out Stress, psi.	Ratio, $\frac{\text{M.B.S.}^a}{\text{M.C.S.}}$	28-day Compressive Strength, psi.
Pilot	....	17 500	1770	59.8	
742 300	23.5	17 800	1800	60.8	
2 112 470	23.5	17 200	1740	58.8	2960
3 830 010	23.5	16 500	1670	56.5	
4 895 740	23.5	16 400	1660	56.1	
Pilot	....	17 500	1770	57.0	
1 120 760	37.2	17 500	1720	55.3	
1 488 010	37.2	Specimens Mishandled			3110
2 160 930	37.2	16 500	1670	53.7	
4 463 630	37.2	15 400	1560	50.1	
Pilot	....	17 500	1770	60.5	
1 198 980	49.8	15 000	1520	51.9	
2 024 650	49.8	13 300	1350	46.1	2930
3 330 720	49.8	11 900	1210	41.3	
4 661 300	49.8	9 650	980	33.4	

[a] R.B.L. = repeated bond load; S.B.L. = static bond load; M.B.S. = maximum bond stress; M.C.S. = maximum compressive stress.

fatigue strength of concrete itself, the bond strength is reduced. From Table V the percentage that each bond stress is of the static unrepeated bond stress may be found for the 5-in. specimens. These are 93.8, 88.1, and 55.4 per cent for repeated loads equal to 23.5, 37.2, and 49.8 per cent, respectively, of the static load. A repeated load equivalent to 55 per cent of the static unrepeated bond load might reduce the bond stress by as much as two-thirds.

The effect of various amounts of repeated load on the bond strength is clearly shown in Fig. 17. In this figure the data contained in Table V and shown in Fig. 16 are replotted for 1, 2, 3, 4, and 5 million cycles of loading. In two cases it was necessary to extrapolate beyond plotted data in order to determine the

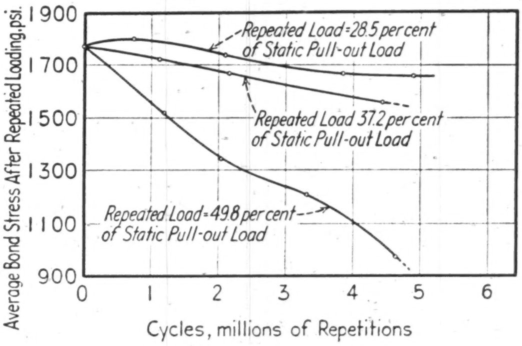

FIG. 16.—Stress-Cycle Diagrams for Three 5-in. Specimens.

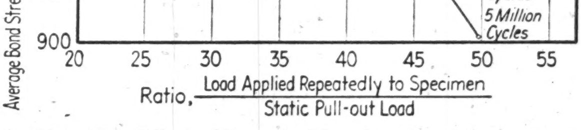

FIG. 17.—Effect of Repeated Load on Bond Strength.

probable stress at 5 million cycles. This family of curves shows that the effect of repeated loading on bond strength is quite pronounced for repeated loads greater than 40 per cent of the static bond strength. This figure may be used in the following manner, for example, for a 5-in. embedment length:

Given:—A ratio of repeated load to static load of 45.0 per cent. A life expectancy of 4,500,000 cycles.

Find:—Maximum bond stress for this condition.

Solution:—From 45.0 per cent load ratio (abscissa) follow vertically upward to an interpolated point of 4,500,000 cycles. Follow horizontally to left and read (on ordinate) an anticipated maximum bond stress of 1290 psi. This value would necessarily need to be modified by a factor of safety in keeping with the permissible movement at first slip.

In Fig. 17, if the curve for 49.8 per cent load was extrapolated beyond the plotted data to a load ratio of 55 per cent, the indicated bond stress would be about one third of the static bond stress. Only additional tests will determine whether the bond stress would actually be this low. As mentioned previously additional tests are necessary to determine whether the stress at 0.001 or 0.0001-in. slip is affected as much as is the maximum stress.

CONCLUSIONS

The data presented as a result of this study seem to warrant the following conclusions:

1. The dead-load type of repeated loading machine described is entirely satisfactory in so far as dependability and accuracy of loading are concerned. No inertia effects are present and none would be anticipated should the speed of loading be doubled.

2. The static pull-out bond stress is decreased when preceded by a repeated pull-out load.

3. The static pull-out bond stress determined after repeated loading decreases with increased repetitions of such load in much the same manner as an endurance-limit diagram used to obtain "fatigue" strength.

4. The higher the ratio (load repeatedly applied to specimen/static pull-out load), the lower the pull-out bond stress after such repetitions.

5. After approximately 4,300,000 repetitions of a stress equal to 23 per cent of the static bond stress, the pull-out bond stress is 84 per cent of the unrepeated value for both 10 and 8-in. embedment lengths.

6. After approximately 4,500,000 repetitions of a stress equal to an average of 35 per cent of the static bond stress, the pull-out bond stress is 88 per cent of the unrepeated value for both 6¼ and 5-in. embedment lengths.

7. After approximately 4,600,000 repetitions of a stress equal to 49.8 per cent of the static bond stress, the pull-out bond stress is 55.4 per cent of the unrepeated value for 5-in. embedment lengths.

8. For repeated bond stresses greater than 40 per cent of the static pull-out bond stress, due allowance should be made for the effect of such repetition and working stresses adjusted accordingly. It would appear that, for a repeated pull-out stress as great as 50 per cent of the static stress and, for short embedments, the reduction should be 50 per cent. For longer embedments and stresses, commensurate with a slip of 0.001 or 0.0001 in., the reduction might not be so great.

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EQUATIONS FOR COMPUTING ELASTIC CONSTANTS FROM FLEXURAL AND TORSIONAL RESONANT FREQUENCIES OF VIBRATION OF PRISMS AND CYLINDERS

By Gerald Pickett[1]

Synopsis

The equations of Mason, Love, etc., that do not take into account the effects of shear are not so satisfactory as Timoshenko's differential equation for flexural (transverse) vibration of prismatic bars. Goens' solution of Timoshenko's differential equation for bars with free ends is in very close agreement with results obtained by means of the mathematical theory of elasticity if the shear constant K' is given the proper value. The proper value depends on Poisson's ratio, being about $\frac{5}{6}$ for $\mu = 0$, $\frac{8}{9}$ for $\mu = \frac{1}{6}$, and 0.85 for $\mu = \frac{1}{3}$. The radius of gyration r adequately describes the cross-section of a prism for the computation of resonant flexural vibration. The approximate equation given by Goens for the correction factor T_1 can be made accurate to at least three figures by subtracting the quantity $125(r/l)^4$.

Equations are given for computing Young's modulus and the shear modulus from flexural and torsional resonant frequencies, respectively.

Graphs are given from which the size and shape factor C in the equation for Young's modulus and Goens' correction factor T are readily determined.

An equation is given for obtaining Poisson's ratio from the flexural and torsional resonant frequencies, and the limitations of the equation are discussed.

Part I—Flexural Vibration

The determination of the resonant frequency for the fundamental mode of flexural vibration of laboratory specimens of concrete has become a routine test in many laboratories (**1–5**).[2] From data on resonant frequency, weight, and dimensions of the specimens, Young's modulus of elasticity is determined by means of formulas such as Eq. 1:

$$E = CWn^2 \qquad (1)$$

where:

E = Young's modulus,
W = weight of the specimen,
n = a resonant frequency, and
C = a factor which depends upon the shape and size of specimen, the mode of vibration, and Poisson's ratio.

Considerable confusion has developed in regard to the formulas used for computing C. Different laboratories have used different formulas and there has been uncertainty as to the assumptions that were made in the derivations of these formulas. An attempt is made in

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 859.

Part I of this paper to clarify this situation and to make available means by which very accurate values of C may be readily obtained. The clarification will be done by:

1. Discussing the various differential equations that have been used for flexural (transverse) vibration of prisms.
2. Discussing the shear constant K' in Timoshenko's differential equation.
3. Comparing the results from Goens' solution of Timoshenko's equation with results obtained by means of the theory of elasticity.[3]

To provide more nearly theoretically correct formulas for C, solutions that satisfy the differential equations of the mathematical theory of elasticity were made for the free vibration of three different shapes of bodies. The bodies were: a thin beam, a wide slab, and a cylinder. The conclusions reached are for the most part based upon results obtained from these theoretical solutions, but in order to keep the mathematical work in this paper relatively simple the solutions are not given. However, the frequency equations resulting from these solutions are given in Appendix I.[4]

DIFFERENTIAL EQUATIONS

The following differential equations have been used for transverse vibration of prismatic bars:

$$\frac{Er_z^2}{\rho}\frac{\partial^4 v}{\partial x^4} + \frac{\partial^2 v}{\partial t^2} = 0 \quad \ldots\ldots\ldots (2)$$

$$\frac{Er_z^2}{\rho}\frac{\partial^4 v}{\partial x^4} + \frac{\partial^2 v}{\partial t^2} - r_z^2\frac{\partial^4 v}{\partial x^2\,\partial t^2} = 0 \ldots (3)$$

$$\frac{Er_z^2}{\rho}\frac{\partial^4 v}{\partial x^4} + \frac{\partial^2 v}{\partial t^2} - r_z^2\frac{\partial^4 v}{\partial x^2\,\partial t^2} + \mu(r_z^2 - r_y^2)\frac{\partial^4 v}{\partial x^2\,\partial t^2} = 0 \,.. (4)$$

$$\frac{Er_z^2}{\rho}\frac{\partial^4 v}{\partial x^4} + \frac{\partial^2 v}{\partial t^2} - r_z^2(1+\mu)\frac{\partial^4 v}{\partial x^2\,\partial t^2} = 0 \ldots (5)$$

$$\frac{Er_z^2}{\rho}\frac{\partial^4 v}{\partial x^4} + \frac{\partial^2 v}{\partial t^2} - r_z^2\left(1 + \frac{E}{K'G}\right)\frac{\partial^4 v}{\partial x^2\,\partial t^2} + \frac{r_z^2\,\rho}{K'G}\frac{\partial^4 v}{\partial t^4} = 0 \,.. (6)$$

where:

ρ = mass per unit volume,
r_z, r_y = radii of gyration of the cross-section with respect to centroidal z- and y-axes, respectively,
v = displacement (deflection) in y-direction,
x = the coordinate in the direction of length,
t = time,
μ = Poisson's ratio,
G = modulus of rigidity (modulus of elasticity in shear), and
K' = a constant introduced by Timoshenko to account for the effect of shear on the slope of the elastic line.

Equation 2 is the elementary equation. The effects of rotatory and lateral inertia and of shear are neglected in its derivation.

Equation 3, given by Rayleigh (7), differs from Eq. 2 in that a term has been added to correct for the effect of rotatory inertia.

Equation 4, given by Love (8) differs from Eq. 3 in that a term has been added to correct for the effect of lateral inertia. This term is never of much importance and is zero for prisms of square cross-section; therefore, its effect can be disregarded in most cases.

Equation 5 is the equation used by Mason (9), and Thomson (10). They state that the term $-\, r_z^2(1 + \mu)\dfrac{\partial^4 v}{\partial x^2\,\partial t^2}$ corrects for both rotatory and lateral inertia and quote Love (8) and Timoshenko (11, 12) as authority. In these details they are in error as may be verified by examining the references cited. Apparently, in obtaining Eq. 5 from Eq. 4, Mason assumed r_y^2 to be negligibly small and inadvertently used the wrong sign for $\mu r_z^2 \dfrac{\partial^4 v}{\partial x^2\, \partial t^2}$. Therefore, all formulas based upon Eq. 5 are of questionable value.

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[3] The expression "theory of elasticity" is used throughout this paper in the restricted sense used by Timoshenko (6). The theory of beams as presented in texts on strength of materials is not included in this use.

[4] See p. 860.

Equation 6, given by Timoshenko (11–13) corrects for the effects of shear and of rotatory inertia. None of the preceding equations corrects for shear;[5] they are therefore considered to be less accurate than Eq. 6. Timoshenko has shown (13) that when the ends are hinged the shear correction is approximately $\dfrac{2(1 + \mu)}{K'}$ times the rotatory inertia correction. It may be shown that for relatively slender specimens with free ends the ratios of the two corrections are approximately $\dfrac{(i + \frac{1}{2})\pi - 2}{(i + \frac{1}{2})\pi + 6} \times \dfrac{2(1 + \mu)}{K'}$, where i is 1, 2, 3, etc., depending on whether the mode of vibration is the first, second, third, etc. For the first mode with free ends the shear correction is about two thirds that of rotatory correction. The ratio becomes higher for the higher modes as the above equation shows.

THE SHEAR CONSTANT K'

The constant K' occurring in Eq. 6 has been a subject of discussion (14). Some investigators use the value $\frac{2}{3}$, the value suggested by Timoshenko for rectangular sections (13); others use $\frac{5}{6}$, the value suggested by Goens (15).

Since in his derivation of Eq. 6 Timoshenko defined K' as the ratio of average unit shear across a section to the unit shear at the neutral axis, it follows on this basis that K' should be $\frac{2}{3}$ for rectangular sections and $\frac{3}{4}$ for circular sections. However, in the derivation Timoshenko considered the effect of shear on slope to be equal to the angle of shear at the neutral axis. In general in static loading the effect of shear on slope is less than the angle of shear at the neutral axis and therefore one would expect K' to be more than $\frac{2}{3}$. By the use of Eqs. (*f*) on page 41 and (*l*) on page 150 of reference 15, one may show that K' should be $\dfrac{20\ (1 + \mu)}{24 + 15\mu}$ and $\frac{5}{6}$, respectively, for the conditions represented by these equations. Equation (*f*) is for a simply supported beam with uniform load and Eq. (*l*) is for a cantilever fixed at one end and loaded at the other end. Other assumptions in regard to loadings and supports would result in other derived values for K'.

Also of importance in a study of the significance of K' is the fact that in his derivation of Eq. 6 Timoshenko neglected the effect of warping of a section on its rotatory inertia. When this effect is taken into consideration in the derivation, the result is an equation identical with Eq. 6 except that the second K' is then defined in terms of the effect of warping on rotatory inertia instead of the effect of shear on slope. However, it turns out that the second K' should have a value approximately equal to $\frac{5}{6}$, that is, about the same value as the first K'.

From the above it appears that K' should be about $\frac{5}{6}$ for rectangular sections. Although these and still further refinements in the derivation of the differential equation would help to establish the best value for K', the most practical answer appears to be to use that empirical value that gives results most nearly in accord with those obtained by means of the mathematical theory of elasticity. With this approach K' can be established within very narrow limits for prisms of rectangular sections and with still greater accuracy for cylinders.

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[5] In the Appendix of reference **10** Thomson gave a differential equation that purported to take shear into account as well as rotatory and lateral inertia. No solution was given and no further use was made of the equation. Thomson erroneously assumed that the relative effects of shear and rotatory inertia could be determined from an examination of the differential equation and therefore decided that an independent solution was not necessary. His assumption would be correct if the ends were hinged but is not correct when the ends are free.

For this purpose solutions based on the mathematical theory of elasticity were made for three different assumptions in regard to shape of body: thin beam, wide slab, and cylinder. The frequency equations derived from these solutions, together with the frequency equation from Goens' (**15**) solution of Eq. 6 for the particular problem at hand—that of the transverse vibrations of a prismatic body with free ends—are given in Appendix I. The derivations of the frequency equations are not given since they are lengthy and beyond the scope of this paper.

FREQUENCY EQUATION OF GOENS VERSUS FREQUENCY EQUATIONS FROM THE MATHEMATICAL THEORY OF ELASTICITY

The equation giving the necessary relation between the resonant frequency and the dimensions, density, and elastic properties of a specimen is called a *frequency equation.* This equation must be known before C in Eq. 1 can be evaluated. The frequency equation that will be found by mathematical derivation depends upon what differential equation (or equations) and what boundary conditions are assumed to hold. If the ends are free, as in the problem under consideration (or, in any case in which the boundary conditions are the same at the two ends), the frequency equation can be reduced to either of the following forms:

$$\frac{M}{\tanh \alpha/2} + \frac{N}{\tan \beta/2} = 0 \ldots\ldots (7)$$

$$\frac{M}{\coth \alpha/2} - \frac{N}{\cot \beta/2} = 0 \ldots\ldots (8)$$

Equation 7 applies to the first, third, fifth, etc., modes of vibration, that is, symmetrical vibration with respect to the plane midway between the two ends. Equation 8 applies to the second, fourth, etc., modes of vibration, that is, asymmetrical vibration. The factors α and β in Eqs. 7 and 8 depend primarily on the ratio of depth in the direction of vibration to length. In Goens' solution the expressions for α and β are determined on the basis of satisfying Eq. 6. In the other three solutions for which frequency equations are given in Appendix I, α and β are determined on the basis of satisfying the requirement that the lateral surfaces be free of stress. The factors M and N are chosen so as to meet the requirement that the ends be free of resultant shear force and resultant moment.[6]

As shown in Appendix I Goens' solution gives expressions for α, β, M, and N explicitly in terms of r/l (reciprocal of slenderness ratio), μ, K', and k. The factor k has a value greater than α and less than β and is related to frequency and other properties by the equation

$$k = \left[\frac{4\pi^2 n^2 \rho l^4}{r^2 E}\right]^{\frac{1}{4}} \ldots\ldots\ldots (9)$$

or

$$E = \frac{4\pi^2 n^2 \rho l^4}{r^2 k^4} \ldots\ldots\ldots (9a)$$

In the other three solutions α and β are the real roots of transcendental equations.

After the factors α, β, M, and N have been found in terms of k for particular values of r/l and μ, substitution can be made in either of Eqs. 7 or 8 as desired and k can be found by trial. The lowest value of k that satisfies Eq. 7 corresponds to the first mode of vibration, the next lowest to the third mode, etc. In the actual computations it was found desirable, especially for the solutions based on the equations of elasticity, first to select a value of $2(1 + \mu)\ (kr/l)^4$, then to determine values of $\alpha r/l$ and $\beta r/l$ as given by the equations for α and β and finally to determine the corresponding value of r/l. An abridged sample computation sheet for $2(1 + \mu)\ (kr/l)^4 = 0.10$ and $\mu = \frac{1}{6}$ is given in Appendix II[7] for each of the four frequency equations given in Appendix I.

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[6] If some other assumption were made in regard to the ends, the expressions for M and N would be different from those given in Appendix I. For example, if the ends were hinged, then $M = 0$ and Eqs. 7 and 8 would reduce to $\tan \beta/2 = \infty$ and $\cot \beta/2 = \infty$. The solution of Eq. 6 for this case is given in reference **13** and solutions by means of the equation of elasticity for plane stress and for plane strain for this case are given in reference **12**.

Computations show that for the same values of r/l and of μ the values of k (and consequently the resonant frequencies of vibration) are only slightly less for plane stress (thin beam) than for plane strain (wide slab). Furthermore, the computations show that for the same r/l and μ the resonant frequency for the cylinder lies between those for plane stress and plane strain, being slightly closer to that for plane stress. Computations also show that for Goens' equation to give results in agreement with those for the cylinder the value of K' should be from 0.83 to 0.90, depending on the value of μ. For μ equal to 0, $\frac{1}{6}$, and $\frac{1}{3}$, the approximate best values of K' are $\frac{5}{6}$, $\frac{8}{9}$, and 0.85, respectively. When, for example, μ is taken equal to $\frac{1}{6}$, the computations show that frequencies computed from Goens' equation with $K' = \frac{8}{9}$ agree to about four significant figures with those for the cylinder. This is true for any value of r/l up to 0.30, the highest ratio investigated.

Although a solution based upon the equations of elasticity has not been obtained for a prism of rectangular section, it seems reasonable that the resonant frequency obtained by such a solution would lie between those for plane stress and plane strain. Probably if the section is nearly square, the frequency would be very close to that of a cylinder of the same r/l.

From the foregoing it is concluded that Goens' equation, with the proper K', is very accurate for either prisms or cylinders and that the radius of gyration r adequately describes the cross-section. Since μ for concrete is usually not far from $\frac{1}{6}$ and the computations show that small variations in μ have relatively little effect on the best value of K', it is concluded that $K' = \frac{8}{9}$ is a good value to use for concrete prisms or cylinders.

EVALUATION OF T AND C

As stated previously, the factor C in Eq. 1 depends on shape and size of specimen, Poisson's ratio, and mode of vibration. From Eqs. 1 and 9a

$$C = \frac{4\pi^2 l^3}{gIk^4} \quad \text{............} \quad (10)$$

where:

g = the acceleration of gravity, and
I = the moment of inertia of the cross-section.

C is thus a dimensional factor, the units of which depend on the units used for l, g, and I. Naturally the units for E in Eq. 1 must be consistent with those for C, W, and n.

In the limit as r/l approaches zero, $\alpha = \beta = k$. Furthermore, $M = N$ in this limit if both ends are free. For this limiting case of r/l approaching zero, Eqs. 7, 8, and 10 reduce to

$$\tan m/2 + \tanh m/2 = 0, \quad \text{....} \quad (7a)$$

$$\cot m/2 - \coth m/2 = 0, \text{ and} \quad \text{...} \quad (8a)$$

$$C' = \frac{4\pi^2 l^3}{gIm^4} \quad \text{..........} \quad (10a)$$

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[7] See p. 863.

respectively, where C' is written for C and m is written for the limiting value of k.

If Eq. 2 were used as the differential equation, the above equations (7a, 8a, and 10a) would be obtained for any value of r/l.

Values of m, accurate to three decimal places, for the first six modes of vibration (obtained by solving Eqs. 7a and 8a) are given below:[8]

$m_1 = 4.730$

$m_2 = 7.853$

$m_3 = 10.996$

$m_4 = 14.137$

$m_5 = 17.279$

$m_6 = 20.420$

The coefficient C' is thus readily obtained if the length l and cross-sectional moment of inertia I are given.

The expression for C can be written as

$$C = C'T \quad \text{.............} (11)$$

where $T\ (= m^4/k^4)$ is the correction factor introduced by Goens (**15**). From the above it is readily seen that T is the factor by which values of C based on Eq. 2, that is, C', should be multiplied in order that C based upon a more accurate differential equation may be found. Consequently, T is the factor by which values of E based on Eq. 2 should be multiplied in order to obtain the E based upon the more accurate differential equation (or equations) under consideration. Since $T = m^4/k^4$ and since m is known, T may be found for any assumed differential equation (or equations) after the corresponding k has been determined. As indicated previously, k is found by trial after α, β, M, and N of the frequency equation have been expressed in terms of k. However, Goens obtained an approximate equation for T in explicit form in terms of r/l, μ, and K' by expanding the frequency equation obtained in his solution in a Taylor series and retaining only the first few terms. When K' is given the values $\frac{5}{6}$, $\frac{8}{9}$, and 0.85, for μ equal to 0, $\frac{1}{6}$, and $\frac{1}{3}$, respectively, then Goens' approximate equation for T reduces to the following:

$$\mu = 0, \quad T_1 = 1 + 79.02(r/l)^2 - \frac{1201(r/l)^4}{1 + 76.06(r/l)^2}$$

$$\mu = 1/6, \quad T_1 = 1 + 81.79(r/l)^2 - \frac{1314(r/l)^4}{1 + 81.09(r/l)^2}$$

$$\mu = 1/3, \quad T_1 = 1 + 88.12(r/l)^2 - \frac{1572(r/l)^4}{1 + 92.61(r/l)^2}$$

The subscript unity signifies that reference is to the first mode of vibration, that is, m in Eq. 10a equals 4.730.

The above values for T_1 agree closely with those obtained by means of the corresponding frequency equation from which the Taylor expansion was obtained for low values of r/l but are a little too large for large values of r/l. Almost exact agreement is obtained, up to a value of $r/l = 0.3$, by subtracting a value equal to $125(r/l)^4$ from the right side of each of the above equations. The agreement is still good for somewhat higher values of r/l, but the derived frequency equations are not reliable for much larger values. This is because the boundary condition that the ends be free was not satisfied rigorously even by the solutions that were based on the theory of elasticity. The resultant shear force and resultant moment at the ends were set equal to zero, but in the derivations not all the forces at the ends were restricted to zero value. This failure to satisfy the end conditions exactly has no appreciable effect on the computed frequency unless the lateral dimension in the direction of motion is considerably larger than the axial dimension. Solutions meeting all boundary conditions exactly would be exceedingly complex and therefore a compromise has to be

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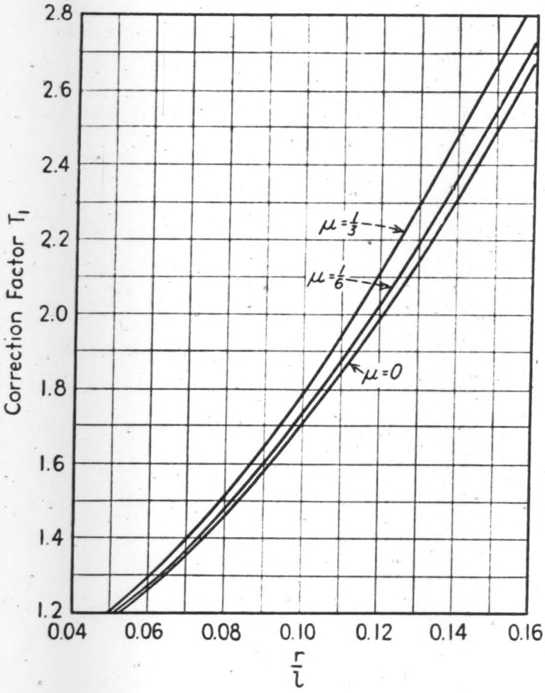
[8] See p. 343 of reference **13**.



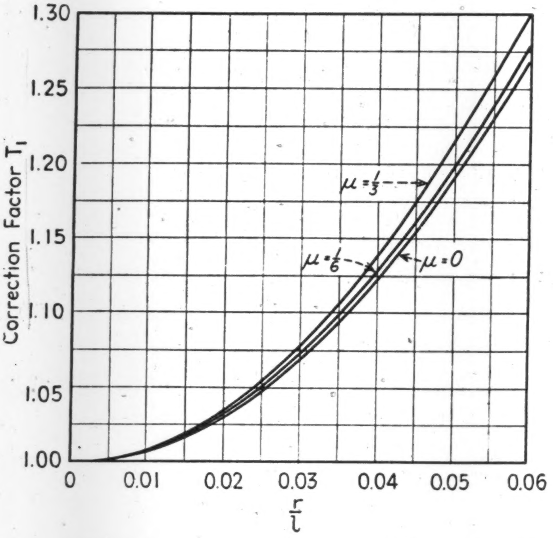
Tabular Values of T_1
Based on Goens' Approximate Equation
Corrected by Subtracting the Factor 125 $(r/l)^4$.

r/l	Correction Factor T_1		
	$\mu = 0$	$\mu = 1/6$	$\mu = 1/3$
0	1.0000	1.0000	1.0000
0.01	1.0079	1.0082	1.0088
0.02	1.0314	1.0325	1.0350
0.03	1.0701	1.0725	1.0780
0.04	1.1234	1.1276	1.1373
0.05	1.1905	1.1969	1.2115
0.06	1.2706	1.2796	1.3003
0.07	1.3632	1.3752	1.4028
0.08	1.4675	1.4829	1.5184
0.09	1.5831	1.6023	1.6466
0.10	1.7095	1.7328	1.7871
0.12	1.9931	2.0262	2.1033
0.14	2.3155	2.3601	2.4646
0.16	2.6739	2.7319	2.8683
0.18	3.0651	3.1385	3.3114
0.20	3.4854	3.5763	3.7902
0.25	4.6351	4.7777	5.1146
0.30	5.8593	6.0660	6.5543

$$\mu = 0, \quad T_1 = 1 + 79.02\left(\frac{r}{l}\right)^2 - \frac{1201(r/l)^4}{1 + 76.06(r/l)^2} - 125\left(\frac{r}{l}\right)^4$$

$$\mu = 1/6, \quad T_1 = 1 + 81.79\left(\frac{r}{l}\right)^2 - \frac{1314(r/l)^4}{1 + 81.09(r/l)^2} - 125\left(\frac{r}{l}\right)^4$$

$$\mu = 1/3, \quad T_1 = 1 + 88.12\left(\frac{r}{l}\right)^2 - \frac{1572(r/l)^4}{1 + 92.61(r/l)^2} - 125\left(\frac{r}{l}\right)^4$$



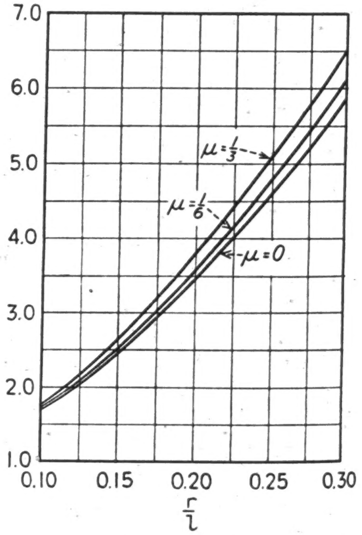


FIG. 1.—Goens' Correction Factor T_1 *versus* Ratio of Radius of Gyration of Section to Length of Prism or Cylinder $\left(\text{Radius of Gyration} = \sqrt{\frac{\text{Moment of Inertia}}{\text{Area}}} = \frac{d}{4} \text{ for cylinder}\right)$.

made. Another compromise would be to satisfy the conditions at the plane ends exactly and permit forces at the curved boundary.

For a cylinder with the diameter greater than the length, a solution based on this compromise would be more accurate than one based on the compromise that was adopted. However, such a solution would be of little practical value since such a specimen would tend to vibrate in some other mode.

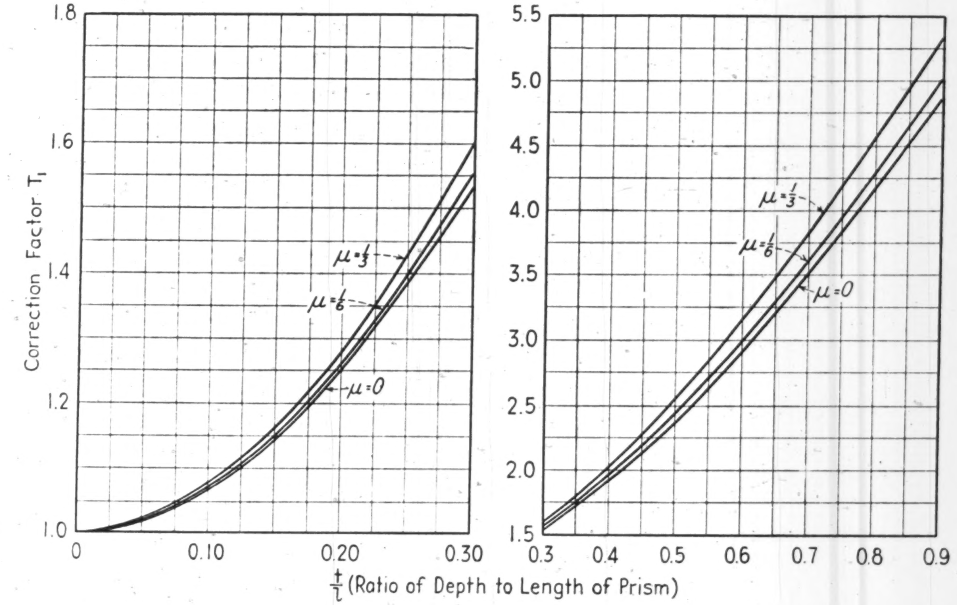


FIG. 2.—Goens' Correction Factor T_1 *versus* Ratio of Depth to Length of Prism.

DESCRIPTION OF CHARTS

Figure 1 shows T for the first mode of vibration, that is, T_1, *versus* r/l (or $d/4l$ for a cylinder) for three different values of Poisson's ratio, 0, $\frac{1}{6}$, and $\frac{1}{3}$.[9]

To simplify the graphical determination of T for prisms of rectangular section, Fig. 2, in which the abscissas are ratios of depth to length (t/l), was prepared.

After T has been determined, the factor C may be computed by means of Eqs. 10a and 11. If the inch-pound-second system is used, then for the first mode of vibration

$$C_1 = 0.00020436 \frac{l^3}{I} T_1 \text{ sec.}^2 \text{ per sq. in.}$$

This reduces to:

$$C_1d = 0.0041632(l/d)^3T_1 \text{ for a circular cylinder,}$$

and to:

$$C_1b = 0.0024523(l/t)^3T_1$$

for a prism of rectangular section, where:

d = diameter of cylinder, and
t, b = dimensions of rectangular section, t being in the direction of vibration.

Plots of C_1d and C_1b *versus* l/d and l/t, respectively, are shown in Fig. 3 for $\mu = \frac{1}{6}$.

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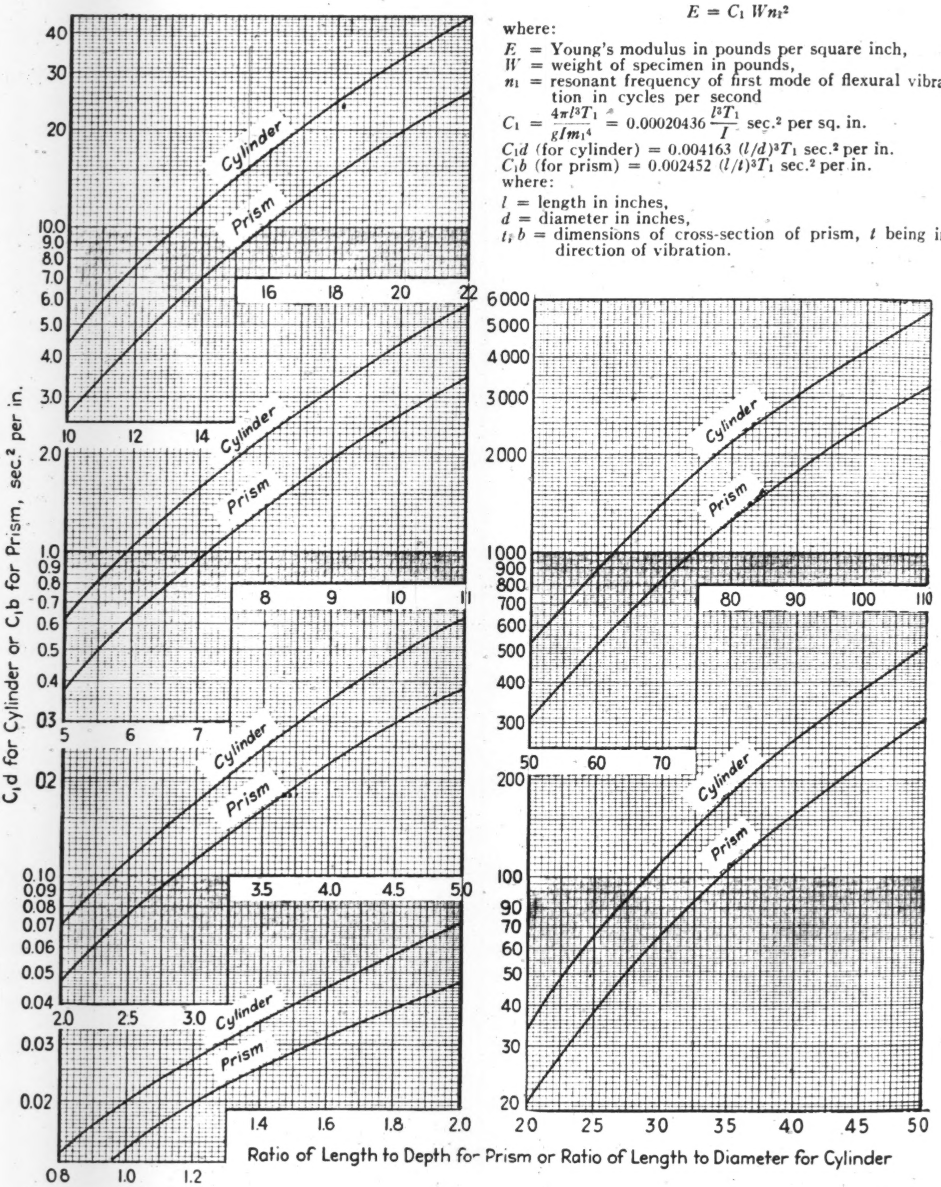
[9] These curves are similar to curves 3 and 4 in Fig. 1 of reference 4. Those in reference 4 were computed from Goens' approximate equation for T_1 with K' equal to 5/6.



$$E = C_1 W n_1^2$$

where:

E = Young's modulus in pounds per square inch,

W = weight of specimen in pounds,

n_1 = resonant frequency of first mode of flexural vibration in cycles per second

$C_1 = \frac{4\pi l^3 T_1}{g I m_1^4} = 0.00020436 \frac{l^3 T_1}{I}$ sec.² per sq. in.

$C_1 d$ (for cylinder) = $0.004163\ (l/d)^3 T_1$ sec.² per in.

$C_1 b$ (for prism) = $0.002452\ (l/t)^3 T_1$ sec.² per in.

where:

l = length in inches,

d = diameter in inches,

t, b = dimensions of cross-section of prism, t being in direction of vibration.

FIG. 3.—Curves for the Graphical Determination of C for Prisms and Cylinders.

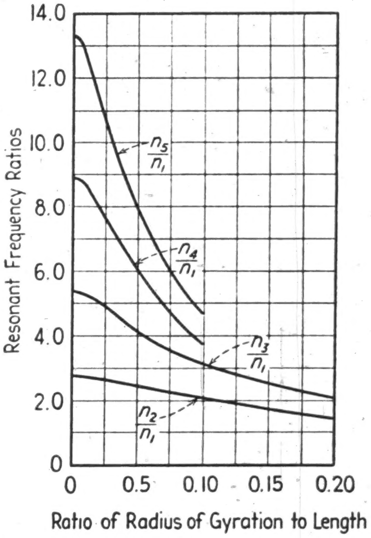


FIG. 4.—Ratios of Resonant Frequencies for Lateral Vibration.

Examples of the Use of Figs. 1, 2, and 3:

(*a*) Find C_1 for a 6 by 6 by 30-in. prism ($\mu = \frac{1}{6}$ assumed).

From Fig. 3

$$C_1 b = 0.392 \text{ sec.}^2 \text{ per in.},$$

therefore

$$C_1 = 0.0653 \text{ sec.}^2 \text{ per sq. in.}$$

or from Fig. 2

$$T_1 = 1.28;$$

therefore

$$C_1 = 0.0024523 \times \frac{30^3}{6^4} \times 1.28$$
$$= 0.0653 \text{ sec.}^2 \text{ per sq. in.}$$

(*b*) Find C_1 for a 6 by 12-in. cylinder.

From Fig. 3

$$C_1 d = 0.070 \text{ sec.}^2 \text{ per in.};$$

therefore

$$C_1 = 0.01167 \text{ sec.}^2 \text{ per sq. in.}$$

or from Fig. 1

$$T_1 = 2.10;$$

therefore,

$$C_1 = 0.0041632 \times \frac{12^3}{6^4} \times 2.10$$
$$= 0.01165 \text{ sec.}^2 \text{ per sq. in.}$$

Values of C_1 for specimens of dimensions either commonly or occasionally used in this laboratory are given in Table I.

HIGHER MODES OF FLEXURAL VIBRATION

Although the first mode of flexural vibration is the more common and the corresponding resonant frequency is the frequency usually obtained in laboratory tests, other modes of flexural vibration, higher than the first, are frequently produced. A specimen may be inadvertently vibrated in a higher mode and if this is not recognized, erroneous results will be obtained. On the other hand, valuable information may be obtained from intentional vibration in higher modes. If values of E determined from two different resonant frequencies determined experimentally on a specimen are

TABLE I.—THE FACTOR *C* IN EQ. 1 FOR THE FIRST MODE OF FLEXURAL VIBRATION AND THE FACTOR *B* IN EQ. 12 FOR THE FIRST MODE OF TORSIONAL VIBRATION FOR SPECIMENS OF CERTAIN DIMENSIONS.

Dimensions, in.[a]	C_1, sec.^{2} per sq. in.	B_1, sec.^{2} per sq. in.
PRISMS		
1 by 1 by 11¼	3.693	0.1379
2 by 2 by 11¼	0.263	0.0345
2 by 2 by 9½	0.169	0.0291
2½ by 2½ by 11¼	0.118	0.0221
3 by 3 by 11¼	0.0625	0.0153
6 by 6 by 21	0.0265	0.00715
6 by 6 by 30	0.0644	0.0102
6 by 6 by 36	0.1043	0.0123
6 by 5¼ by 34	0.1022	0.0136
5¼ by 6 by 34	0.1282	0.0136
4 by 3 by 16	0.0732	0.0178
3 by 4 by 16	0.1144	0.0178
4 by 4 by 16	0.0549	0.0123
3 by 6 by 15	0.0644	0.0157
6 by 3 by 15	0.0250	0.0157
3 by 2 by 37	2.415	0.0885
2 by 3 by 37	5.294	0.0885
CYLINDERS		
6 by 12	0.0117	0.00440
6 by 18	0.0284	0.00660
8 by 16	0.00874	0.00330
3 by 6	0.0233	0.00880
6 by 6	0.00333	0.00220
6 by 9	0.00670	0.00330
3 by 3	0.00666	0.00440

[a] The first dimension is the thickness in the direction of flexural vibration.

not in good agreement, then either the corresponding modes of vibration were not the ones assumed for the computations or the formulas used were not applicable to the specimen under investigation. Occasional checking in this regard is recommended and Fig. 4 was prepared for this purpose.

Figure 4 makes it unnecessary to have charts for the higher modes similar to those of Figs. 1, 2, and 3 for the first mode. To find the value of E from data on the resonant frequency of a higher mode, all that is necessary is first to convert to an equivalent first-mode frequency by dividing by the ratio given by Fig. 4 and then to proceed as described above for determining E from the frequency of the first mode.

It was of course necessary to evaluate T_2, T_3, T_4, T_5, C_2, C_3, C_4, and C_5 over appropriate ranges of r/l preparatory to the construction of Fig. 4. In making these evaluations Goens' frequency equation with $\mu = \frac{1}{6}$ and $K' = \frac{8}{9}$ was used. Some use was also made of Goens' approximate equation for T which, for the higher modes, reduces to the following equations:

$$T_2 = 1 + 229.81(r/l)^2 - \frac{9984(r/l)^4}{1 + 223.6(r/l)^2}$$

$$T_3 = 1 + 446.51(r/l)^2 - \frac{38372(r/l)^4}{1 + 438.3(r/l)^2}$$

$$T_4 = 1 + 735.17(r/l)^2 - \frac{104853(r/l)^4}{1 + 724.5(r/l)^2}$$

$$T_5 = 1 + 1095.24(r/l)^2 - \frac{233979(r/l)^4}{1 + 1082.3(r/l)}$$

Like the Goens equation for T_1 the above equations give values in close agreement with the values obtained from the frequency equation directly if only relatively low values of r/l are considered. They differ from the equation for T_1 in that for higher values of r/l they give values too small whereas as noted previously the Goens' equation for T_1 gives values too large. If the term $100{,}000\ (r/l)^6$ is added to the equation for T_2 and $26{,}000(r/l)^5$ is added to the equation for T_3, these two equations will be reliable up to a value of r/l equal to 0.20. The equations for T_4 and T_5 are not reliable beyond $r/l = 0.05$ and the additional terms necessary to increase their range have not been worked out.

DOUBLE HUMP IN RESONANCE CURVE

A problem sometimes develops in regard to flexural vibration from the fact that there are two directions, perpendicular to each other, for flexural vibration. If the resonant frequencies for these two directions are equal or approximately equal, and if the specimen has some kind of non-symmetry, the modes for these frequencies will be coupled. This results in the so-called "double hump" in the curve representing response *versus* frequency. When this occurs, the tester is sometimes in doubt as to which frequency to record or whether to record the average of the two. Sometimes this question can be decided on the basis of information in regard to the torsional resonant frequency for the specimen, as will be explained after torsional vibration and Poisson's ratio have been discussed.

PART II—TORSIONAL VIBRATION

Prisms and cylinders may be caused to vibrate in torsion as well as flexure. In fact a specimen assumed to be vibrating laterally may be vibrating in torsion to the confusion of the tester unless he knows how to identify the various modes of vibration. The main purpose of Part II of this paper is to present the appropriate formulas giving the relation between resonant frequencies in torsional vibration of the body and the weight, dimensions, and shear modulus.

The general formula for shear modulus corresponding to Eq. 1 for Young's modulus is as follows:

$$G = B\,W(n')^2 \quad \text{.........} (12)$$

where:

n' = a torsional frequency,

$B = \dfrac{4\,l\,R}{g\,A\,i^2}$,

A = cross-sectional area,

i = unity for first mode, two for second, etc., and

R = ratio of polar moment of inertia to the shape factor for torsional rigidity.

The ratio R is unity for a circular cylinder and 1.183 for a prism of square section. Its approximate value for rectangular sections is given by the formula[10]

$$R = \frac{a/b + b/a}{4a/b - 2.52(a/b)^2 + 0.21(a/b)^6} \quad \text{..} (13)$$

where:

a = the length of the shorter side, and

b = the length of the longer side of the cross-section.

The factor R may be determined for a section of any shape from the relation

$$R = \frac{\iint (x^2 + y^2)\,dx\,dy}{\iint F(x, y)\,dx\,dy} \quad \text{.....} (14)$$

where the integrations are taken over the section and the function $F(x,y)$ is equal to zero on the boundary of the section and satisfies the equation

$$\frac{\partial^2 F}{\partial x^2} + \frac{\partial^2 F}{\partial y^2} + 4 = 0$$

within the boundary.[11]

Values of B for the first mode, that is, B_1, for specimens of dimensions commonly used in this laboratory, are given in Table I along with the values of C_1.

PROCEDURE FOR EXPERIMENTAL DETERMINATION OF RESONANT TORSIONAL FREQUENCIES

The determination of both torsional and flexural resonant frequencies of laboratory specimens requires very little work in addition to that required to determine only flexural resonant frequencies. For best response of the specimen to induced torsional vibration the driver should be placed at one end in such a manner as to produce maximum torque. Since this position is also a favorable position for inducing flexural vibration, both torsional and flexural resonant frequencies of a specimen may be found without changing position of specimen, "driver" or "pick-up." The only disadvantage in placing the driver at one end when only the resonant frequency for first mode of flexural vibration is desired is that it is also a favorable position for exciting other modes of vibration that might be mistaken for the first mode of flexural vibration. For best results the specimen should be supported on soft rubber. If the supports are sufficiently flexible, their location is immaterial. If the supports are relatively rigid, then the supports should be placed at nodes.

IDENTIFICATION OF MODES

If there is doubt as to the mode of vibration, the mode can usually be identified by locating the nodes. The position of the nodes in torsional vibration is the same as in longitudinal vibration, that is, one node at the center for the first mode, two nodes at $l/4$ and $3l/4$ from one end for second mode, three nodes at $l/6$, $l/2$, and $5l/6$ for third mode, etc. For flexural vibration there will be one more node than the order of the mode. For the same number of nodes they will be spaced slightly differently from the spacing in torsional vibration, that is, for two nodes one will be at approximately $0.23l$ from either end instead of $0.25l$ and for three nodes one will be at the center and one approximately $0.14l$ from either end. The position of the nodes in flexural vibration depends slightly on the r/l value but is not affected nearly as much as was indicated by Thomson (**10**).

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[10] See equation for torsional rigidity of rectangular sections given by Roark (**16**).

[11] See Chapter 9 of reference 6.

Also of assistance in identifying torsional modes is the fact that the resonant frequency of a particular torsional mode is equal to the order of the mode times that of the first torsional mode. Figure 4, discussed previously, is useful in identifying modes of flexural vibration. As shown by Fig. 4, the ratios of the resonant frequencies of the higher modes of flexural vibration to those of the first are not simple integers.

POISSON'S RATIO

Poisson's ratio for a homogeneous isotropic solid is related to E and G by the equation

$$\mu = \frac{E}{2G} - 1 \ldots\ldots\ldots\ldots (15)$$

or from Eqs. 1 and 12

$$\mu = \frac{C}{2B}\left(\frac{n}{n'}\right)^2 - 1 \ldots\ldots\ldots (15a)$$

Therefore Poisson's ratio may be determined dynamically if the specimen is sufficiently homogeneous and isotropic.

The lack of homogeneity resulting from differences in the elastic properties of the constituents (hydrated cement paste, unhydrated clinker, aggregate, and air and water voids) of concrete does not appear to affect appreciably the validity of Eqs. 15 and 15a. Probably bleeding and the segregation that must take place at molded and finished surfaces during placing result in slightly different resonant frequencies of the specimen than would be obtained if the specimen were prepared from the same mix without the occurrence of bleeding and segregation.

These non-homogeneities might change the flexural resonant frequency a different percentage than they change the torsional and thereby result in a change in μ as computed by Eq. 15a. These effects, as well as any resulting from lack of isotropy, are believed to be of negligible importance in laboratory specimens of good concrete unless the specimens have been weakened by frost action or cracking resulting from excessive shrinkage or thermal stresses. Equation 15a may have little meaning if the specimen is badly cracked or considerably deteriorated by frost action.

Equation 15a is not to be used for aeolotropic materials such as wood, some rock cores, or reinforced concrete. As explained by Love in Chapter VI of his book (**8**), an aeolotropic material with no plane of symmetry is characterized by 21 elastic constants. If the aeolotropic material has a number of planes of symmetry, the number of elastic constants may be reduced to 13, 9, 7, 6, 5, or 3, depending on the number of planes of symmetry and their orientation. It is only an isotropic material, one in which every plane is a plane of symmetry, that can be characterized by two elastic constants such as Young's modulus and Poisson's ratio. Consequently, frequency equations derived for an isotropic specimen might not be applicable to an aeolotropic specimen. Frequency equations that were based upon a particular type of aeolotropy might prove to be very useful in investigating the elastic constants of a material of that particular type of aeolotropy.

We have not had sufficient experience to justify definite statements as to the importance of Poisson's ratio in dynamic testing of concrete. Poisson's ratio usually decreases on drying of specimens and increases as the specimens absorb moisture. It increases as hydration proceeds and was found to be greater than 0.25 for specimens molded under pressure. Experience may show that changes in Poisson's ratio during storage may be of significance in interpreting the effects of the conditions of storage.

SELECTION OF MODE OF VIBRATION

As indicated previously, it may be desirable to obtain both flexural and torsional resonant frequencies of the same specimen. However, specimens may be of such shape that one or the other frequency is difficult to obtain with equipment at hand. For example, it was found to be very difficult to induce first or second mode of torsional vibration in specimens of 2 by 3 by 37-in. size. Higher modes such as third, fourth, and fifth were induced without difficulty. On the other hand, if r/l is greater than 0.10, the first mode of torsional vibration is much easier to excite than the first mode of flexural vibration.

If for any reason only one resonant frequency is to be obtained, a factor to be kept in mind in making the decision as to whether it should be that of flexural vibration or of torsional vibration is the fact that the frequency equations for torsional vibration are usually not restricted to as small values of r/l as are the frequency equations for flexural vibration.[12] Therefore, a specimen of which the axial dimension is about equal to or somewhat less than the smaller of the lateral dimensions may be tested for G when it is impractical to test for E. However, if the axial dimension is much smaller than the lateral, then the specimen may be vibrated in flexure as a thick plate. The frequency equation, obtained by means of the equations of elasticity, for the flexural vibration of a thick disk is similar to that given in Appendix I for flexural vibration of a cylinder. Further details in this regard are beyond the scope of this paper.

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[12] If the specimen is cylindrical, Eq. 12 is theoretically correct for any value of r/l. If the specimen is not cylindrical Eq. 12 is slightly in error but the present writer is of the opinion that except for perhaps prisms of rather oblong cross section of the percentage of error for a given r/l will be less than the percentage of error in the equations for flexural vibration.

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APPENDIX I

FREQUENCY EQUATIONS FOR FLEXURAL VIBRATION

General Form of Equation:

$$\frac{M}{\tanh \alpha/2} + \frac{N}{\tan \beta/2} = 0 \text{ for 1st, 3rd, etc., modes}$$

$$\frac{M}{\coth \alpha/2} - \frac{N}{\cot \beta/2} = 0 \text{ for 2nd, 4th, etc., modes}$$

α, β, M, and N are functions of r/l, k, and μ

where:

$k = \left[\frac{4\pi^2 n^2 \rho l^4}{r^2 E}\right]^{\frac{1}{4}}$,
μ = Poisson's ratio,
ρ = mass density,
E = Young's modulus,
r = radius of gyration of section,
l = length, and
n = frequency.

I. *Goens' Solution:*

$$\alpha = k[(B^2k^4 + 1)^{\frac{1}{2}} - Ak^2)^{\frac{1}{2}}, \qquad \beta = k[(B^2k^4 + 1)^{\frac{1}{2}} + Ak^2]^{\frac{1}{2}}$$

$$M = \alpha/k^2\,[(B^2k^4 + 1)^{\frac{1}{2}} + Bk^2], \qquad N = \beta/k^2[(B^2k^4 + 1)^{\frac{1}{2}} - Bk^2]$$

where:

$$A = (r/l)^2\left[\frac{1+\mu}{K'} + \frac{1}{2}\right],$$

$$B = (r/l)^2\left[\frac{1+\mu}{K'} - \frac{1}{2}\right], \qquad \text{and}$$

K' = shear constant; should be $\frac{5}{6}$, $\frac{8}{9}$, 0.85, respectively, for μ equal to 0, $\frac{1}{6}$, $\frac{1}{3}$.

II. *Plane Stress* (*Thin Beam*), and
III. *Plane Strain* (*Wide Slab*):

$$\alpha = \text{the real root of}\left[f^2 + \left(\frac{\alpha r}{l}\right)^2\right]^2 \tan\frac{hc}{r} = 4fh\left(\frac{\alpha r}{l}\right)^2 \tan\frac{fc}{r}$$

$$\beta = \text{the real root of}\left[(f')^2 + \left(\frac{\beta r}{l}\right)^2\right]^2 \tanh\frac{h'c}{r} = 4f'h'\left(\frac{\beta r}{l}\right)^2 \tanh\frac{f'c}{r}$$

$$M = \frac{\dfrac{2h^2 - f^2 + \left(\dfrac{\alpha r}{l}\right)^2}{4h^2}\left[\tan\dfrac{hc}{r} - \dfrac{hc}{r}\right] - \dfrac{\left(\dfrac{\alpha r}{l}\right)^2}{f^2 + \left(\dfrac{\alpha r}{l}\right)^2}\left[\tan\dfrac{fc}{r} - \dfrac{fc}{r}\right]}{\dfrac{\alpha}{2}\left[\tan\dfrac{hc}{r} - \tan\dfrac{fc}{r}\right]}$$

$$N = \frac{\dfrac{2(h')^2 - (f')^2 + \left(\dfrac{\beta r}{l}\right)^2}{4(h')^2}\left[\tanh\dfrac{h'c}{r} - \dfrac{h'c}{r}\right] - \dfrac{\left(\dfrac{\beta r}{l}\right)^2}{(f')^2 + \left(\dfrac{\beta r}{l}\right)^2}\left[\tanh\dfrac{f'c}{r} - \dfrac{f'c}{r}\right]}{\dfrac{\beta}{2}\left[\tanh\dfrac{h'c}{r} - \tanh\dfrac{f'c}{r}\right]}$$

where:

For plane stress:	For plane strain:
$h = \left[\left(\frac{\alpha r}{l}\right)^2 + (1-\mu^2)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$	$h = \left[\left(\frac{\alpha r}{l}\right)^2 + \frac{(1+\mu)(1-2\mu)}{1-\mu}\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$
$f = \left[\left(\frac{\alpha r}{l}\right)^2 + 2(1+\mu)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$	$f = \left[\left(\frac{\alpha r}{l}\right)^2 + 2(1+\mu)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$
$h' = \left[\left(\frac{\beta r}{l}\right)^2 - (1-\mu^2)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$	$h' = \left[\left(\frac{\beta r}{l}\right)^2 - \frac{(1+\mu)(1-2\mu)}{1-\mu}\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$
$f' = \left[\left(\frac{\beta r}{l}\right)^2 - 2(1+\mu)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$	$f' = \left[\left(\frac{\beta r}{l}\right)^2 - 2(1+\mu)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$

$$c = \text{half depth of beam} = \sqrt{3}\,r$$

IV. *Circular Cylinder:*

$$\alpha = \text{the real root of } \begin{vmatrix} a_1, & b_1, & c_1 \\ a_2, & b_2, & c_2 \\ a_3, & b_3, & c_3 \end{vmatrix} = 0$$

$$\beta = \text{the real root of } \begin{vmatrix} a'_1, & b'_1, & c'_1 \\ a'_2, & b'_2, & c'_2 \\ a'_3, & b'_3, & c'_3 \end{vmatrix} = 0$$

$$M = \frac{a_4c_5 + c_1b_5}{\alpha/2(a_5c_5 - b_4b_5 - c_3c_4)}, \qquad N = \frac{a'_4c'_5 + c'_1b'_5}{\beta/2(a'_5c'_5 - b'_4b'_5 - c'_3c'_4)}$$

where:

$$a_1 = \frac{J_1(2h)}{h} - J_0(2h) - \left[f^2 + \left(\frac{\alpha r}{l}\right)^2\right]\frac{J_1(2h)}{h},$$

$$a'_1 = \frac{iJ_1(2ih')}{h'} + J_0(2ih') + \left[(f')^2 + \left(\frac{\beta r}{l}\right)^2\right]\frac{iJ_1(2ih')}{h'}$$

$$a_2 = 2\left[\frac{J_1(2h)}{h} - J_0(2h)\right] \qquad a'_2 = 2\left[\frac{iJ_1(2ih')}{h'} + J_0(2ih')\right]$$

$$a_3 = \frac{J_1(2h)}{h} - 2J_0(2h) \qquad a'_3 = \frac{iJ_1(2ih')}{h'} + 2J_0(2ih')$$

$$a_4 = \frac{2h^2 - f^2 + \left(\frac{\alpha r}{l}\right)^2}{4h^2}\, a_2 \qquad a'_4 = \frac{2(h')^2 - (f')^2 + \left(\frac{\beta r}{l}\right)^2}{4(h')^2}\, a'_2$$

$$a_5 = \frac{J_1(2h)}{h} \qquad a'_5 = \frac{iJ_1(2ih')}{h'}$$

$$b_1 = \frac{J_1(2f)}{f} - J_0(2f) - 2fJ_1(2f) \qquad b'_1 = \frac{iJ_1(2if')}{f'} + J_0(2if') + 2f'iJ_1(2if')$$

$$b_2 = 2\left[\frac{J_1(2f)}{f} - J_0(2f)\right] \qquad b'_2 = 2\left[\frac{iJ_1(2if')}{f'} + J_0(2if')\right]$$

$$b_3 = \frac{f^2 + \left(\frac{\alpha r}{l}\right)^2}{\left(\frac{\alpha r}{l}\right)^2}\left[\frac{J_1(2f)}{2f} - J_0(2f)\right] \qquad b'_3 = \frac{(f')^2 + \left(\frac{\beta r}{l}\right)^2}{\left(\frac{\beta r}{l}\right)^2}\left[\frac{iJ_1(2if')}{2f'} + J_0(2if')\right]$$

$$b_4 = \frac{\left[f^2 + \left(\frac{\alpha r}{l}\right)^2\right]\frac{J_1(2f)}{2f}}{\left(\frac{\alpha r}{l}\right)^2} \qquad b'_4 = \frac{\left[(f')^2 + \left(\frac{\beta r}{l}\right)^2\right]\frac{iJ_1(2if')}{2f'}}{\left(\frac{\beta r}{l}\right)^2}$$

$$b_5 = a_1 c_2 - a_2 c_1 \qquad b'_5 = a'_1 c'_2 - a'_2 c'_1$$

$$c_1 = -\frac{J_1(2if)}{f} + J_0(2f) \qquad c'_1 = -\left[\frac{iJ_1(2if')}{f'} + J_0(2if')\right]$$

$$c_2 = -2\left[\frac{J_1(2f)}{2f} - J_0(2f) - fJ_1(2f)\right] \qquad c'_2 = -2\left[\frac{iJ_1(2if')}{f'} + J_0(2if') + f'iJ_1(2if')\right]$$

$$c_3 = -\frac{J_1(2f)}{2f} \qquad c'_3 = -\frac{iJ_1(2if')}{2f'}$$

$$c_4 = a_1 b_2 - a_2 b_1 \qquad c'_4 = a'_1 b'_2 - a'_2 b'_1$$

$$c_5 = b_1 c_2 - b_2 c_1 \qquad c'_5 = b'_1 c'_2 - b'_2 c'_1$$

$$h = \left[\left(\frac{\alpha r}{l}\right)^2 + \frac{(1+\mu)(1-2\mu)}{1-\mu}\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}} \qquad h' = \left[\left(\frac{\beta r}{l}\right)^2 - \frac{(1+\mu)(1-2\mu)}{1-\mu}\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$$

$$f = \left[\left(\frac{\alpha r}{l}\right)^2 + 2(1+\mu)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}} \qquad f' = \left[\left(\frac{\beta r}{l}\right)^2 - 2(1+\mu)\left(\frac{kr}{l}\right)^4\right]^{\frac{1}{2}}$$

APPENDIX II

ABRIDGED SAMPLE COMPUTATION SHEET FOR $2(1+\mu)\left(\frac{kr}{l}\right)^4 = 0.10$ and $\mu = \frac{1}{6}$

	Goens' Solution for $K' = \frac{8}{9}$	Plane Stress	Plane Strain	Cylinder
VALUES FOUND BY TRIAL				
$\alpha\, r/l$	0.36366	0.36055	0.35767	0.36349
$\beta\, r/l$	0.53629	0.53863	0.53494	0.53574
k	4.0209	4.016	4.0473	4.0210
r/l	0.11316	0.11335	0.11242	0.11316
COMPUTED VALUES BASED ON ABOVE TRIAL VALUES				
α	3.2137	3.1808	3.1816	3.2117
β	4.7392	4.7520	4.7582	4.7344
M	0.23500	0.23606	0.23669	0.23416
N	0.24794	0.24658	0.24557	0.24841
CHECK OF FREQUENCY EQUATION				
$M/\tanh \alpha/2$	0.25469	0.25653	0.25720	0.25382
$N/\tan \beta/2$	−0.25469	−0.25653	−0.25720	−0.25392
Sum	0.00000	0.00000	0.00000	−0.00010
OTHER VALUES COMMON TO THE SOLUTIONS BASED ON THEORY OF ELASTICITY				
h	....	0.41433	0.40980	0.41488
h'	....	0.49846	0.49615	0.49699
f	....	0.47958	0.47742	0.48179
f'	....	0.43604	0.43147	0.43243

OTHER VALUES OCCURRING IN PROBLEM OF CYLINDER

$J_0(2h)$	+0.83514	$J_1(2h)/h$	+0.91636	$hJ_1(2h)$	+0.15773
$J_0(2f)$	+0.78100	$J_1(2f)/f$	+0.88838	$fJ_1(2f)$	+0.20622
$J_0(2ih')$	+1.26267	$iJ_1(2ih')/h'$	−1.12869	$ih'J_1(2ih')$	−0.27879
$J_0(2if')$	+1.19592	$iJ_1(2if')/f'$	−1.09646	$if'J_1(2if')$	−0.20504
a_1	−0.25256	b_1	−0.30506	c_1	−0.10738
a_2	+0.16244	b_2	+0.21476	c_2	+0.19768
a_3	−0.75392	b_3	−0.92852	c_3	−0.44419
a_4	+0.05763	b_4	+1.22455	c_4	−0.004686
a_5	+0.91636	b_5	−0.032483	c_5	−0.037243
a'_1	−0.40102	b'_1	−0.31062	c'_1	−0.09946
a'_2	+0.26796	b'_2	+0.19892	c'_2	+0.21116
a'_3	+1.39665	b'_3	+1.06970	c'_3	+0.54823
a'_4	+0.16110	b'_4	−0.90544	c'_4	+0.003463
a'_5	−1.12869	b'_5	−0.058028	c'_5	−0.045809

CHECK ON EQS. FOR α AND β

	Plan Stress	Plane Strain	Cylinder	
α				
$\tan(hc/r)$	0.87288	0.85914	$a_1b_2c_3$	+0.024093
$\tan(fc/r)$	1.09485	1.08673	$a_2b_3c_1$	+0.016196
$[f^2 + (\alpha\, r/l)^2]^2$	0.12960	0.12664	$a_3b_1c_2$	+0.045465
$4fh(\alpha\, r/l)^2$	0.10333	0.10012	$-a_1b_3c_2$	−0.046357
Left side	0.11313	0.10880	$-a_2b_1c_3$	−0.022011
Right side	0.11313	0.10880	$-a_3b_2c_1$	−0.017386
Difference	0.00000	0.00000	Sum	0.000000
β				
$\tanh(h'\, c/r)$	0.69797	0.69592	$a'_1b'_2c'_3$	−0.043733
$\tanh(f'\, c/r)$	0.63825	0.63360	$a'_2b'_3c'_1$	−0.028509
$[(f')^2 + (\beta\, r/l)^2]^2$	0.23066	0.22310	$a'_3b'_1c'_2$	−0.091607
$4f'h'(\beta\, r/l)^2$	0.25224	0.24504	$-a'_1b'_3c'_2$	+0.090582
Left side	0.16099	0.15526	$-a'_2b'_1c'_3$	+0.045631
Right side	0.16099	0.15526	$-a'_3b'_2c'_1$	+0.027632
Difference	0.00000	0.00000	Sum	−0.000004

DISCUSSION

Mr. William T. Thomson[1] (*by letter*).—Mr. Pickett is to be congratulated for his thoroughness in his investigation and for clarifying the various assumptions upon which previous solutions have been based.

In regard to Eqs. 3, 4, 5, and 6, they are identical mathematically provided the last term of Eq. 6 is omitted. It should be noted that in the discussor's paper,[2] all the equations were developed on the basis of Eq. 3, which correctly accounts for the rotatory inertia. The extension to include the lateral inertia and shear was then assumed possible by examination of the differential equation. Unfortunately the relative effect of shear cannot be evaluated by examination of the differential equation as pointed out by Mr. Pickett. The reason for this lies in the fact that the coefficients in the shear boundary equation do not appear in the same form as that in the differential equation.

In regard to the double hump in the resonance curve, such humps can be produced by coupling between two modes. In the case of flexure-torsion coupling, the two coupled frequencies are given by the following equation which may be obtained from the study of normal modes.

$$\omega_{1,2}^2 = \frac{(\omega_f^2+\omega_t^2) \pm \sqrt{(\omega_f^2+\omega_t^2)^2 - 4\omega_f^2\omega_t^2(1-C^2)}}{2(1-C^2)}$$

where:

ω_f = circular frequency in flexure,

ω_t = circular frequency in torsion,

$$C_2 = \frac{[\int s \cdot y(x) \cdot O(x)\, dm]^2}{\int y^2(x)\, dm \cdot \int O^2(x)\, dJ}$$

= coupling factor,

s = eccentricity of the center of gravity, and $y(x)$ and $O(x)$ = normal modes in flexure and torsion.

The above equation would require the two coupled frequencies to be outside the two uncoupled frequencies. Of particular interest is the case when $\omega_f = \omega_t = \omega$. The coupled frequencies then reduce to $\omega_{1,2}^2 = \omega^2 \frac{1 \pm C}{1 - C^2}$ and the double hump is evident.

Another item of interest is concerned more with the practical aspects of designing proper vibration equipment for producing and measuring vibrations. The requirements of the driver depend on the facilities available for measuring these vibrations which can be specified by the sensitivity in terms of the amplitude. Having established the amplitude necessary for measurement, the size of the driving unit necessary is approximately independent of the size of the structure to be vibrated as long as resonant frequencies are of primary concern. This statement may sound paradoxical until the facts are carefully examined as follows:

Assuming harmonic motion, the power required to vibrate a structure can be shown to be equal to $P = \frac{1}{2} F y_0 \omega$ where

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[1] Design Specialist in Charge of Vibration and Flutter Analysis, Ryan Aeronautical Co., San Diego, Calif.

[2] W. T. Thomson, "The Effect of Rotatory and Lateral Inertia on Flexural Vibration of Prismatic Bars," *Journal*, Acoustical Soc. Am., Vol. 11, p. 198 (Oct. 1939).

F is the damping force. For solid damping such as that encountered in structural materials, the damping force is approximately independent of frequency, proportional to the amplitude, and 180 deg. out of phase with the velocity. The magnitude of the damping force can therefore be expressed as: $F = cy_0\ \omega_f^2 \int y^2(x)\ dm$ where c is a nondimensional damping coefficient defined as the ratio of the damping force to the elastic force which has been replaced in terms of the inertia force by considering uncoupled motion. Substituting this expression in the equation for power, $P \cong \frac{1}{2}\ c\ \omega^3\ y_0^2 \int y^2(x)\ dm$.

Considering geometrically similar structures of length ratio n, it can be shown that the resonant frequencies will be inversely proportional to the length, or $\omega_l = \frac{1}{n}\ \omega_s$ where l and s refer to the large and small structures. Since the mass of the structure varies as n^3, the power required to vibrate a structure with a specified amplitude at resonance remains independent of the size of the structure—that is at resonance a given driver will produce equal amplitudes in the small and large specimen.

Similar analysis is applicable to the torsional motion with the same conclusion. The ratio of the power required for equivalent amplitudes will, however, be proportional to the cube of the frequency ratio.

$$\frac{P\ \text{(torsional resonance)}}{P\ \text{(bending resonance)}} \propto \left(\frac{\omega_t}{\omega_f}\right)^3$$

MR. GERALD PICKETT (*author's closure, by letter*).—Mr. Thomson's discussion in regard to flexure-torsion coupling and in regard to the power required to vibrate geometrically similar structures has added to the paper. It is my opinion, however, that in case the cause of the coupling is some local structural weakness rather than eccentricity of the center of gravity, the equation for C^2 should be modified.

For some problems, the last term in Eq. 6 can be omitted without introducing appreciable error, but for the problems here considered, this term contributes a considerable fraction of the total correction.

TEST CRITERION FOR AN INCOMBUSTIBLE MATERIAL

By N. P. Setchkin[1] and S. H. Ingberg[1]

Synopsis

The term "incombustible," while in recognized use as indicating materials that will not ignite or burn, is indefinite in its application unless referenced to a well-defined testing procedure. Among testing methods, that adopted by the British Standards Institution, British Standard 476—1932, appeared to have the most promise of achieving the intended purpose. By this method the sample is heated gradually during the course of 1½ hr. in a vertical electrically-heated furnace tube up to a temperature of 1382 F. (750 C.), and observations made of occurrence of flame, self-induced glow, or of gases that can be ignited by a pilot flame.

Tests of a considerable number of materials were made by this method, including asbestos insulations with up to about 10 per cent of combustible constituents, acoustical and heat-insulating materials with a larger range in combustible content, and samples of magnesium, aluminum, aluminum alloys, tin, and zinc, in a range in particle sizes. The tests were conducted according to the British Standard and also, using the same equipment, by a modified method, involving heating the equipment to the final temperature, 1382 F., before introduction of the sample.

The term "incombustible" is used in building codes and other regulations and in specifications often without being defined. An incombustible material means to the user of the word a material that will not burn under conditions of exposure which he has in mind. It will not necessarily have the same meaning to others unless those conditions are defined. Thus, most metals will burn under certain conditions, and minor amounts of combustible constituents in an otherwise incombustible material will give it properties inconsistent with those intended when incombustibility is specified.

In a survey of the field of definitions and testing methods, those adopted by the British Standards Institution appeared to have the most promise of achieving the intended purpose. These are given in British Standard Definitions for Fire Resistance, Incombustibility and Noninflammability of Building Materials and Structures (Including Methods of Test) (British Standard 476–1932).

A sketch of the equipment for the incombustibility test is given in Fig. 1 (substantially the same as Fig. II in the British standard). The following is quoted from the above standard:

"Incombustibility Test of Materials

"6. (*a*) *Size of Specimens.*—Materials for subjection to the incombustibility test shall be 2 in. × $1\frac{1}{2}$ in. × T (50.8 mm. × 38.1 mm. × T), where T is the normal thickness in inches of the material if under $1\frac{1}{2}$ in. (38.1 mm.). Where the thickness of the material is over $1\frac{1}{2}$ in. (38.1 mm.) the test specimens shall be cut to a thickness of $1\frac{1}{2}$ in. (38.1 mm.).

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[1] Associate Mechanical Engineer and Principal Materials Engineer, respectively, National Bureau of Standards, Washington, D. C.

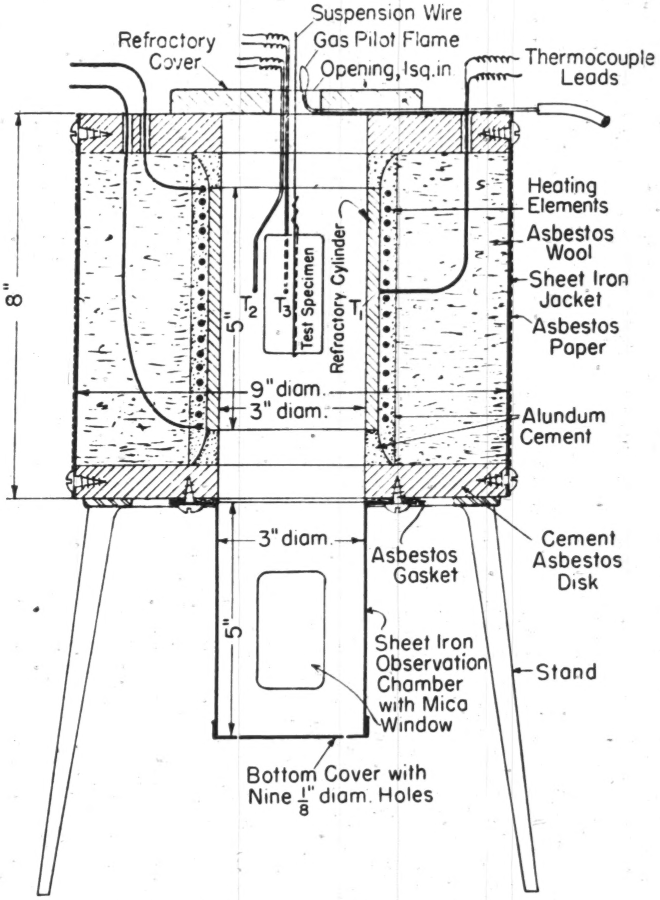
Suspension Wire
Gas Pilot Flame
Refractory Cover
Opening, 1sq.in.
Thermocouple Leads
Heating Elements
Asbestos Wool
Sheet Iron Jacket
Asbestos Paper
Test Specimen
Refractory Cylinder
T2
T3
T1
8"
5"
9" diam.
3" diam.
Alundum Cement
3" diam.
5"
Asbestos Gasket
Cement Asbestos Disk
Sheet Iron Observation Chamber with Mica Window
Stand
Bottom Cover with Nine 1/8" diam. Holes

FIG. 1.—Apparatus for Incombustibility Tests.

"*(b) Number of Specimens.*—The number of specimens to be tested shall be at the discretion of the testing authority.

"If the first three specimens tested are found to be incombustible as set forth in paragraph (3) no more need be tested. If any specimen tested be found to be combustible on the same standard (paragraph (3)) no further tests need be made and the material shall be deemed combustible.

"*(c) Conditioning.*—The test specimens shall be dried by heating at 212 F. (100 C.) for six hours.

"*(d) Method of Test.*—The test specimens shall be fixed centrally in the heating tube of the apparatus shown in Fig. II with its long axis vertical, and shall be supported throughout the test.

"A light stirrup of nichrome wire, supported by a length of nichrome wire passing through the slit in the adjustable cover, may be used for supporting the specimen.

"During the test the adjustable cover

shall be so arranged that there is an opening about 1 sq. in. (6.45 sq. cm.) in area below the pilot flame.

"The apparatus is heated by passing a suitably regulated source of electric current through the nichrome resistance wire surrounding the heating-tube.

"The temperature of the tube shall then be increased by 900 F., or 500 C., per hour at as uniform a rate as possible. The test shall be discontinued when a temperature of 1382 F. (750 C.) has been reached.

"The temperature of the tube shall be taken as that shown by a thermo-couple situated at the level of the center of the specimen and equidistant from the inner surface of the heating-tube and the middle of one of the $1\frac{1}{2}$ in. (38.1 mm.) wide sides of the specimen. The wires of which the thermo-couple is made shall be between 18 and 26 S.W.G. thickness, and shall be bare for a length of 1 in. (25.4 mm.) from the junction.

"(*e*) *Standard of Incombustibility.*—A material shall not be considered to be incombustible within the meaning of clause 2 of this specification if at any time during the test period the specimen:—

(i) flames,

or

(ii) glows brighter than the walls of the heating-tube, and, if glowing at all, the glow does not immediately diminish when the specimen is lowered to the center of the observation chamber"

EQUIPMENT AND TESTING METHODS

To obtain information experimentally on the application of the method, equipment was constructed substantially in accord with the given British standard except that the enclosure for the insulation around the furnace chamber was made round instead of square. Also, to obtain better information on the self-heating within the specimen, three thermocouples were used, No. 1 on the outside of the refractory furnace tube, No. 2 attached to the sample with the couple on or near its surface, and No. 3 in the middle of the sample. Tests were conducted with temperature rise of the furnace as indicated by thermocouple No. 2 following the British standard, namely, a uniform rate of rise of about 900 F. (500 C.) per hr., reaching a final temperature of 1382 F. (750 C.) in about $1\frac{1}{2}$ hr. This gradual heating did not, however, induce ignition of materials, the properties of which were otherwise indicated as not consistent with what should be expected of an incombustible material.

With a rising temperature, minor amounts of combustible constituents may oxidize or char so slowly that no evidence of flame, self-induced glow, or explosion appears. The Bureau's experimental work on the ignition temperatures of materials has shown that better indications of ignition can be obtained by plunging the specimen into a preheated furnace than by gradual heating. Accordingly, in addition to making tests as defined in the British standard, tests were also made by raising the temperature within the furnace tube to 1382 F. (750 C.) before introducing the specimen. To make convenient the introduction of the test sample the refractory cover was made in two pieces. Powdered samples were in copper mesh containers.

SUMMARY OF RESULTS

(*a*) *Asbestos Insulations:*

Tests according to the above methods were made with corrugated asbestos paper insulations that had been applied as insulation in prefabricated chimneys for temporary demountable emergency housing. These were placed with an air space over enameled metal flue pipes within which flue gas temperatures of 1000 F. or more might obtain when connected to heating equipment burning solid fuels. Under these conditions it was found in the use and tests of these installations that self-heating and glow

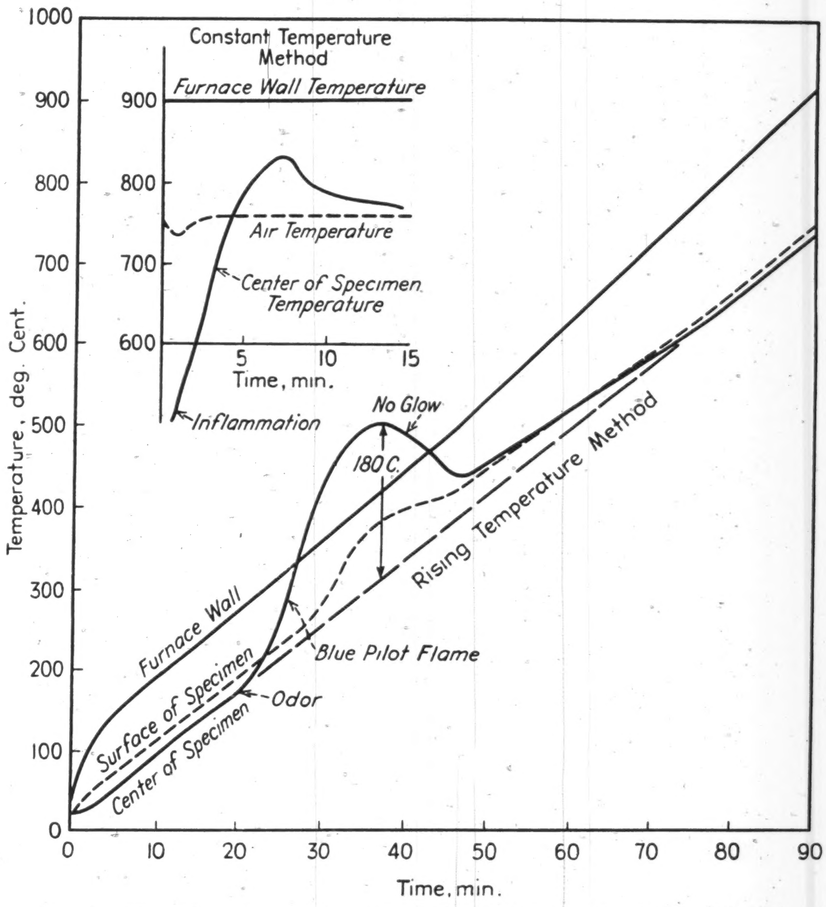

FIG. 2.—Time-Temperature Curves for Chimney Asbestos Insulation (BS – 31).

TABLE I.—INCOMBUSTIBILITY TESTS OF ASBESTOS CHIMNEY INSULATIONS BY BRITISH STANDARD METHOD AND MODIFIED METHOD.

Sample size, 2 by 1½ in. by thickness, latter not over 1½ in.

Mark	Outside finish	Carbon, per cent		Total Loss in Weight at 1832 F., per cent	British Method		Modified Method	
		Total	Organic		Ignition	Self-Heating, deg. Fahr.	Ignition	Self-heating, deg. Fahr.
INDICATED AS INCOMBUSTIBLE BY BOTH METHODS								
N-8	Asbestos	0.8	0.5	14.5	None	None	None	None
N-4	Asbestos	1.0	0.5	14.4	None	None	None	None
BS-8	Painted	2.5	1.7	18.8	None	None	None	None
BS-5a	Painted	2.4	1.4	17.6	None	90	None	None
BS-5b	Asbestos	1.8	1.4	17.3	None	158	None	None
BS-3	Asbestos	2.2	2.0	18.2	None	144	None	None
INDICATED AS INCOMBUSTIBLE BY BRITISH METHOD BUT NOT BY BUREAU METHOD								
BS-31	Paper	4.0	3.5	22.8	None	324	Flame and glow	137
BS-4	Paper	3.9	Not determined	21.2	None	313	Flame and glow	234
BS-7b	Paper	5.0	4.6	24.1	None	464	Flame	252
BS-33	Paper	5.4	5.1	25.6	None	481	Flame	144
BS-27	Asbestos	5.2	4.5	25.6	None	545	Flame and glow	252

would be induced in insulations containing more than very minor amounts of combustible materials such as wood fiber or starch. This heating resulted in high surface temperatures which caused ignition of any combustible covering or combustible material in contact with the chimney.

The results of the tests are given in Table I. The determination of total carbon was made by burning a sample in a tube furnace in oxygen at 1832 F. (1000 C.), the carbon being computed from the weight of carbon dioxide and carbon monoxide given off. This is subject to a correction for the carbon from inorganic carbonates that may have been present, determined by prolonged digestion in hot dilute hydrochloric acid. The difference was taken as the carbon from organic compounds. From the carbon content the content of combustible constituents can be computed. Thus, the starch or cellulose content, both of molecular formula $C_6H_{10}O_5$, will be about $2\frac{1}{4}$ times that of the organic carbon content. The loss on ignition at 1832 F. (1000 C.) is from the combined water in the asbestos fiber as well as the carbon of organic and inorganic origins.

TABLE II.—INCOMBUSTIBILITY TESTS OF ACOUSTICAL TILES BY BRITISH STANDARD METHOD AND MODIFIED METHOD.

Sample size 2 by 1½ in. by thickness, latter not over 1½ in.

Mark[a]	Classification per Federal Specification SS-A-118	Carbon, per cent		Total Loss of Weight at 1832 F.	British Method		Modified Method	
		Total	Organic		Ignition	Self-heating, deg. Fahr.	Ignition	Self-heating, deg. Fahr.
INDICATED AS INCOMBUSTIBLE BY BOTH METHODS								
J	Incombustible	0.5	0.1	5.0	None	None	None	None
S	Incombustible	1.7	1.0	4.9	None	None	None	None
H	Incombustible	7.9	0.6	29.3	None	None	None	None
R	Incombustible if without paper covering	4.9	1.6	20.2	Glow in paper only	259	Flame in paper only	None
INDICATED AS INCOMBUSTIBLE BY BRITISH METHOD BUT NOT BY BUREAU METHOD								
U	Incombustible	6.0	3.1	37.5	None	122	Flash	54
F	Fire-retardant	6.9	6.5	16.2	None	869	Flame	180
C	Fire-retardant	11.4	Not determined	19.6	None	851	Flame	270
INDICATED AS NOT INCOMBUSTIBLE BY BOTH METHODS								
T	Slow-burning	16.2	Not determined	16.2	Flame	1202	Flame	270

[a] The principal constituents of the acoustical tiles are as follows:
J. Expanded slag aggregate with portland cement binder.
S. Mineral wool with sodium silicate binder.
H. Lime and silica foaming agent.
R. Gypsum and foaming agent, covered with corrugated heavy paper on one side.
U. Compressed asbestos wool with cement and casein paint on one side.
F. Mineral wool bound with starch.
C and T. Compressed mineral wool with asphalt binder.

It is seen from Table I that all of the samples of asbestos insulation would be rated as incombustible by the British method of testing but that by the modified procedure involving initial heating of the furnace to 1382 F., only those insulations containing 2 per cent or less by weight of organic carbon were so rated. The ignition was indicated by appearance of flame and glow in the sample. The gases given off by the specimen were not ignited by the pilot flame nor did they cause ignition of the specimen although at times they gave color to the flame.

In Fig. 2 are given the temperature curves from the test at rising temperature and at constant temperature for specimen BS-31 containing 3.5 per cent of carbon of organic origin. It is seen that with the test conducted according to the British Standard, there was considerable self-heating, beginning at a temperature of about 300 F. (150 C.) but the rise was not high enough to cause ignition. With the constant-temperature method, the rise of temperature within the specimen was very rapid and ignition occurred within a few minutes.

(*b*) *Acoustical Tiles:*

In Table II are given the results with acoustical tiles obtained by the same methods as are outlined above. In the table are also given the classification of these tiles as tested according to Federal Specification SS-A-118 for Prefabricated Acoustical Units.

In the test under the Federal Specification the specimen, 3 by 3 ft., is mounted in a horizontal position on an angle frame enclosing an area of 30 by 30 in. A flame from a $\frac{7}{8}$-in. gas-air burner is directed against the center of the specimen, the top of the burner being 28$\frac{3}{4}$ in. below the specimen. The intensity of the fire exposure is gaged with a thermocouple placed 1 in. below the center of the specimen. For materials to be classed as "incombustible" or "fire-retardant" the more severe exposure following the "Columbia" time-temperature curve is used, and for classification of "slow-burning" or "combustible" the less severe exposure with indicated temperatures following the standard curve. The duration of the test for the former is 40 min., and for the other, 20 min. To classify as other than "combustible" no flame from the specimen must reach the angle frame during or after flame application nor shall glow progress to the edge of the specimen. For the "incombustible" classification no flame shall issue from the specimen and the glow shall not progress beyond the fire-exposed area. To qualify as "Fire-retardant" any flaming must be limited to short intermittent flashes. All flaming shall cease within 2 min. after the test flame is discontinued for the "fire-retardant" classification, and within 5 min. to qualify for the "slow-burning" class.

The determinations of total carbon and organic carbon were made as previously indicated. The total loss at 1832 F. includes combined water given off at this temperature but not in the preliminary drying at 220 F. In the case of samples *C* and *T*, the organic carbon was not determined, but the total carbon was probably in large part from the asphalt binder.

It is seen (Table II) that by the British method materials containing over 6 per cent of organic carbon are rated as incombustible, whereas by the Bureau method none with over 2 per cent are so classified. The sample R without the paper covering would be classed as incombustible by both methods, but not with the paper.

The accord between the results of these tests and those conducted according to Federal Specification SS-A-118 is as good as can be expected for widely differing methods. It is recognized that with the method of the Federal Specification it is difficult to distinguish between a highly fire-retardant and an incombustible material.

(*c*) *Metals:*

In Table III are given results of ignition tests, using the British apparatus, by both the rising and constant tem-

TABLE III.—IGNITION TESTS WITH METALS

All samples of approximately 3 g. weight unless otherwise noted.

Material	Particle Size, Sieve Number		British Apparatus Rising Temperature Method		British Apparatus Constant Temperature Method		1000-ml. Flask Constant-Temperature Method
	Passed	Retained on	Ignition	Temperature of Furnace Air, deg. Fahr.	Ignition	Temperature of Furnace Air, deg. Fahr.	Self-Ignition Temperature, deg. Fahr.
Magnesium, cast	Single piece 2 by 1½ by ½ in. (35 g.)		Flame	1144	...	...	...
Magnesium, cast	Single piece		Flame	1081	Flame	1078	1076
Magnesium ribbon	One coil		Flame	1049	Flame	1004	1004
Magnesium powder	30	50	...	...	...	...	950
	50	70	...	...	...	...	946
	70	100	...	...	...	...	943
	70	200	...	...	...	...	939
	100	200	Flame	959	Flame	941	936
	200	325	...	...	...	...	918
	325	...	...	...	...	...	883
Aluminum filings		70	None	(Up to 1670)	None	(Up to 1562)	...
	70	200	None	(Up to 1652)	None	(Up to 1594)	...
Aluminum filings plus 2 per cent stearic acid	70	200	...	...	None	1382	...
Aluminum filings plus 5 per cent stearic acid	70	200	...	...	None	1382	...
Aluminum paint powder (1 per cent stearic acid coating)	100	200 (41 per cent)	Flame	1076	Flame	959	...
Aluminum paint powder (2 per cent stearic acid coating)	100	200 (41 per cent)	Flame	1004	Flame	959	...
The above, washed in ethyl ether and alcohol (0.7 per cent stearic acid left)	100	200 (41 per cent)	...	...	Flame	1382	...
Atomized aluminum powder	81.5 per cent pass 325		...	...	None	1382	...
Ultra fine aluminum powder	From 5 to 20 microns		Flame	1256	Flame	1382	...
Duralumin powder	70	100	None	(Up to 1382)	None	1382	...
	100	200	None	(Up to 1382)	None	1382	...
Aluminum plus 5 per cent silicon	70	200	None	(Up to 1382)	None	1382	...
Aluminum alloy (Cu Si Fe)	70	200	None	(Up to 1382)	None	1382	...
Tin chips (20 g sample)		70 (Avg. 1 g.)	...	...	None	1382	...
Tin drillings (15 g sample)		70 (Avg. 0.014 g.)	None	(Up to 1382)	None (70 F. rise)	1382	...
Tin powder		70	Dull glow (270 F. rise)	1094	Bright glow	1094	...
		100	Dull glow (306 F. rise)	1076	Bright glow	1076	...
	100	200	Bright glow (430 F. rise)	968	Bright glow	968	...
	200	325	None (144 F. rise)	(Up to 1382)	Bright glow	842	...
Zinc nuggets (20-g. sample)	Avg. weight 1.2 g.		None	(Up to 1382)	None	1382	...
Zinc chips (20-g. sample)		70 (Avg. 1 g.)	None	(Up to 1382)	None	1382	...
Zinc drillings (15-g. sample)		(Avg. 0.01 g.)	None	(Up to 1382)	Flame	1382	...
Zinc powder	...	70	None	(Up to 1382)	Flame	1382	...
	100	200	None	(Up to 1382)	Flame	1382	...
	200	...	Flame	1202	Flame	1202	...
	200	300	None	(Up to 1382)	Flame	1382	...
Iron, carbonyl	325	...	...	...	None	1562	...
Iron, electrolytic	325	...	...	...	None (250 F. rise)	1544	...
	325	...	...	...	None	1634	...

perature methods. In the last column of the table are also given the self-ignition temperature of magnesium as determined in a test tube inserted in a 1000-ml. flask maintained at given constant temperatures. Air at the temperature of the flask is drawn through the sample at a rate determined by trial to give the lowest self-ignition temperature. The self-ignition temperature is the lowest initial temperature of the sample and flask contents from which self-heating resulting in ignition will occur, as evidenced by flame, explosion, or self-sustained glow.

Since it was known from previous work that ignition of magnesium would occur at lower temperatures than 1382 F. (750 C.), the tests in the British apparatus were made at lower temperatures, ignition using the constant temperature method being obtained at nearly the same temperatures as in the 1000-ml. flask with a sample of comparable size. With the rising temperature method, the temperatures causing ignition were somewhat higher.

The aluminum in the various samples was, as far as known, of the commercial degree of purity or about 99.2 per cent aluminum. Some samples were prepared for the tests by sieving filings from aluminum castings, the particles being more or less spherical, cubical, or rectangular in shape. The paint powders were flat and coated and polished with stearic acid, applied in part by mechanical rubbing and agitation to form a uniform and homogeneous coating. The atomized aluminum powder is produced by dispersing molten aluminum with steam or compressed air jets.

It is seen (Table III) that no ignition was obtained with aluminum filings, the tests being extended with temperatures considerably above the 1382 F. limit for the British test. Ignition was, however, readily obtained with the aluminum paint powders coated with stearic acid to the extent 1 or 2 per cent by weight. Attempts to remove the stearic acid coating were only partially successful. The powder, with residual coating approximating 0.7 per cent of its weight, ignited nearly as readily as the original material. An attempt was made to increase the combustibility of the fine aluminum filings by coating to the extent of 2 and 5 per cent of the weight with stearic acid dissolved in ethyl ether and evaporated while agitating the mixture. While a flash of flame was obtained from the coating, the aluminum did not ignite and was only partly oxidized. This leaves open the question of whether the paint powder ignited because the flat shape of the particles gave a relatively large ratio of surface to volume, and the extent to which ignition was induced by the coating.

The only ignition of uncoated aluminum powder was obtained with the ultra fine atomized sample of particle size less than 0.001 in. In the fineness tested, three aluminum alloys, with samples obtained by sieving fine filings from the cast material, did not ignite at furnace temperatures up to 1382 F.

Ignition as evidenced by intense glow was obtained with powdered tin at temperatures in the range 842 to 1094 F., depending on fineness and testing method. These should not necessarily be regarded as the lowest or self-ignition temperatures, but they suffice to show that under the conditions of the constant temperature method, ignition occurs at temperatures considerably below 1382 F. In one test by the rising temperature method, the fine powder did not ignite, possibly because of oxidation at the lower temperatures at a rate that did not induce ignition. In this as in some of the other tests not resulting in the bright glow indicating ignition, there was self-heating of the sample to temperatures considerably above that of the furnace air. No ignition was obtained with two samples of tin chips and drillings, the particles of which averaged 1 g. and 0.014 g. in weight, respectively.

Samples of zinc nuggets, made by dropping molten zinc into water, did not ignite nor did zinc chips or drillings except for particle size averaging 0.01 g. with which ignition was obtained by the constant temperature method. With the powder samples ignition was obtained by one or both methods, the occurrence of flame being a more definite evidence of ignition than the glow observed with tin. With the rising temperature method the finest powder did not ignite, possibly for the reason indicated in the case of the fine tin powder.

No ignition occurred with the two kinds of fine iron powder as tested under constant temperatures up to 1634 F. Considerable self-heating was observed, recorded in one test as 250 F. above the furnace temperature.

DISCUSSION

The results herewith submitted indicate the possibility of defining an incombustible material in terms of performance tests such as those outlined above. No definition in terms of chemical composition would be generally applicable. Minor amounts of combustible constituents do necessarily give performance inapplicable for an incombustible material and the permissible percentage thereof apparently is dependent on the nature of the components and possibly other factors such as state of subdivision and distribution.

The correlation in the performance of the materials in the incombustibility tests as given in Tables I and II, and in the larger scale chimney and acoustical tile tests referred to above, is as satisfactory as can be expected. This is true particularly for the constant temperature test condition with initial heating of the test chamber to 1382 F. (750 C.) before introduction of the sample. It is also appreciated that without a very uniform distribution of the combustible content, a sample taken for carbon determination and the incombustibility tests may not be fully representative of the larger samples subjected to the other tests, which may give rise to minor apparent inconsistencies.

The application of the results to metals can be made under two categories, one concerning members, pieces, and particles larger than powder or dust, and the other, the fire and explosion hazard of a mass or cloud of the more or less finely divided material. Under the former, the results with magnesium indicate that it cannot be considered an incombustible material because ignition was obtained even with as large a sample as required under the British specification. Ignition of aluminum was obtained only with coated powder or very fine uncoated powder, and hence, as judged by the present procedure it can be taken as incombustible if not in powder or dust form. The same applies for the aluminum alloys included in the tests which did not include alloys with magnesium except for duralumin containing less than 2 per cent thereof. With iron, no ignition was obtained even with the fine powder, hence a similar conclusion is justified. Tin and zinc ignited only in samples of particle size corresponding to coarse or finer powders and then only consistently as tested by the constant temperature method. In the usual form of sheets and coatings they have not been indicated as a fire hazard under fire exposure in structures in which they are used or in fire tests of component parts of such structures.

At the other end of the scale of particle size, the tests conducted and the method as such should not be taken as indicative of all conditions and degrees of fire and explosion hazard of metal powders and dusts. The tests concerned were included to show that incombustibility with one particle size does not necessarily mean that the same material in a more finely divided condition will not ignite under the same conditions. It is also noted that no tests were included with samples representative of material dispersed as dust clouds.

IGNITION TEMPERATURE DETERMINATIONS FOR LIQUIDS AND GASES

While the present tests and discussion have been concerned only with the ignition properties of solids, the extent to which similar test methods are applicable to liquids and gases may be of interest. Several methods have been used for the determination of the self-ignition temperature of liquids, the most consistent results from the standpoint of fire and explosion hazards being obtained by injecting a sample into a chamber heated to a given constant temperature, with size of sample and chamber proportioned within practical limits to give conditions most favorable for ignition. After a brief initial drop in temperature within the chamber, the temperature will rise to or beyond the initial temperature, depending on whether there is any self-heating within the mixture. If such occurs, it may heat it up to a given temperature and then recede without ignition or the self-heating may continue up to the point where ignition as evidenced by flame or explosion will occur. The self-ignition or autogenous ignition temperature is defined as the lowest initial temperature of the gas-air mixture in the chamber from which it will self-heat up to the point where ignition occurs. It is thus seen that the method is comparable with the constant temperature method for solids described above.

Similar methods have been applied for gases as well as some involving flow of the mixture through heated tubes during the ignition reaction. In no case have self-ignition temperatures higher than 1382 F. (750 C.) been found for liquids and gases by any method that can be regarded as indicating ignition due to self-heating rather than from contact with hot surfaces or other extraneous sources of ignition.

DISCUSSION

MR. HYLTON R. BROWN[1] (*by letter*).—As stated in the first paragraph of this paper, the term "incombustible" may have different meanings depending on a number of conditions. This is particularly evident in connection with tests involving metals or metal powders. The authors point out that all of the metals included in these tests with the exception of magnesium may be classified as incombustible unless the material is in the form of finely divided metal powder, and some of the metal powders in quiescent layers may also be classified as "incombustible" under accepted methods of testing, although it is well-known that most metals will burn under certain conditions and metal-powder explosions and fires have caused extensive loss of life and property. The conditions noted apparently indicate the necessity of distinguishing between block specimens and powdered or finely divided forms of the same material in any definition or statement on the combustibility or incombustibility. It also seems particularly desirable as a safety measure to incorporate in any statement on the combustibility or incombustibility of such products a warning that certain powders which do not ignite readily in layers may be ignited by comparatively weak static sparks when they are in suspension in air as a cloud and under such conditions may produce a violent explosion.

The ignition temperatures reported for some of the metal powders check quite closely with those reported by other investigators, but in several cases considerable differences are noted. For instance, the ignition temperature reported for one of the samples of tin powder is identical with that given by Irving Hartmann,[2] but the ignition temperature reported for the sample of ultrafine aluminum powder is more than 400 F. higher than that obtained by Hartmann in tests with the same product some time ago in a different type of furnace. It is also interesting to note that the authors were unable to obtain ignitions of carbonyl iron or electrolytic iron at temperatures up to 1562 F. and 1634 F., respectively, when ignitions of quiescent layers of similarly designated powders have been obtained by other investigators with different apparatus at temperatures below 750 F.

The authors mention one test in which oxidation at lower temperatures may have been responsible for the failure to obtain ignition. Other investigators have had similar experiences. In one case where a number of samples of freshly milled metal powder were weighed and left exposed on a table while ignition tests were being made, the readings obtained were progressively higher as the tests proceeded and the difference was believed to have been due to oxidation. The ultrafine aluminum powder supplied to the authors for these tests was not a fresh sample and this fact may explain the higher ignition temperature readings obtained.

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[1] Senior Engineer, Bureau of Mines, U. S. Department of the Interior, College Park, Md.
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[2] Irving Hartmann, "Inflammability and Explosibility of Metal Powders," Bureau of Mines Report of Investigations 3722.

Another apparently important factor in combustibility tests with powdered products is touched on only briefly. For one group of powders tested, the authors report that the rate of air flow through and around the sample was determined by trial to give the lowest self-ignition temperature. C. R. Brown[3] deals more extensively with this subject and points out that for each material or possibly class of material there is a certain rate of air flow that should give minimum values.

In addition to distinguishing between block specimens and powder samples in reports on combustibility, it appears to be necessary to incorporate in any standardized test to determine the combustibility of a powdered product some provision for the control of air flow through and around the sample. It is also evident that length of exposure to air or slow heating of samples at temperatures below the ignition point should be considered in drawing any conclusions from the results of combustibility tests with metal powders.

MESSRS. SETCHKIN AND INGBERG (*authors' closure by letter*).—The present paper is concerned mainly with the investigation of a testing method for defining a combustible material rather than determining how any considerable range in variety or condition of materials will be classified by the test. A reservation thereon is made in the paper with particular reference to metal powders. Mr. Brown indicates that the degree of oxidation thereof is an important consideration although the low ignition temperature he cites for iron powder may be in part due to differences in apparatus and testing methods.

It is also to be noted that the method does not necessarily determine the lowest self-ignition temperature. The size of specimen, design of the apparatus, and method of operation is fixed by the specification covering a method such as the one under discussion. This applies particularly as it concerns the air flow which is governed by the design of the equipment. In the determination of self-ignition temperature, the air flow and size and condition of specimen are varied so self-heating resulting in ignition will be initiated at the lowest temperature attainable with the equipment. While some of the tests with the apparatus as reported in Table III were made at higher or lower temperatures, all others were made at constant or final temperature limit of 1382 F. (750 C.) taken as the criterion of incombustibility.

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[3] C. R. Brown, "The Determination of the Ignition Temperatures of Solid Materials," Catholic University of America, Washington, D. C. (1934).

FATIGUE TESTS OF A LAMINATED MITSCHERLICH-PAPER PLASTIC

By William N. Findley[1]

Synopsis

Two methods of fatigue testing applicable to laminated plastics are described, and the results of fatigue tests of a Mitscherlich-paper laminate are reported. Fatigue tests on rotating-beam type fatigue machines show the effect of speeds of testing, from 500 to 14,000 rpm., on the fatigue strength. Results of fatigue tests obtained with the same type of machine show the effect of temperature from −75 F. to +400 F. on the fatigue strength. The effect of a notch on the fatigue strength of this material is also shown.

Data obtained with a fatigue machine of the constant amplitude-of-deflection type show the effect of different ranges of stress on the fatigue strength in bending, and also the effect of different ranges of stress on the fatigue strength in torsion.

High-strength laminated plastics are currently of considerable interest, as load-carrying parts, in semi-structural applications in aircraft, ships, and other military equipment. Much interest is also being expressed in the potential use of such materials for structural components of aircraft. Many of the current and potential uses of these materials are in applications in which the materials must resist repeated loadings as well as static loads, so that the fatigue characteristics of these materials are of real importance.

The tests reported in this paper constitute a study of the mechanical characteristics of a high-strength paper-base laminate, molded from Mitscherlich-type paper. This is the concluding portion of a report on a comprehensive series of mechanical tests of this laminate. In a previous paper (**1**)[2] the short-time static properties and creep properties of the material were reported.

Several investigators have reported fatigue tests of various types of plastics. The materials tested have included several thermoplastic materials (**2, 3, 4, 5**) phenolic molding materials with different types of fillers (**6, 7, 8, 9**) and different types of laminated plastics (**8, 10, 11, 12, 13**). One investigator has reported fatigue tests of a high-strength laminated paper plastic at room temperature for completely reversed stress cycles (**10**).

As far as the author has been able to determine the present series of tests includes the only available results of fatigue tests of plastics at temperatures above room temperature, at temperatures as low as −75 F., and of torsion fatigue tests of plastics in which the effect of range of stress was studied.

MATERIAL

The laminate for these tests was supplied by the Taylor Fiber Co., in December, 1942, and was made of high-strength Mitscherlich paper bonded under low pressure with a low-pressure type of phenolic resin. The Mitscherlich paper was made from wood pulp by the sulfite process. Data on the manufacturing conditions and materials used in preparing this laminate are described in detail in the previous paper on tests of this laminate (1).

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[1] Assistant Professor of Theoretical and Applied Mechanics, College of Engineering, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 902.

SPECIMENS

The specimens used for the fatigue tests in this investigation are shown in Fig. 1. All specimens were cut from the sheet in such a way that the long axis of the specimens was parallel to the grain of the paper used in the laminate. The test sections were prepared by turning on a lathe, using tools of high-speed steel, whose cutting edges were maintained razor sharp by repeated honing. The 2-in. radius used on specimens *a* and *c* was produced by swinging the compound of the lathe by means of a tangent screw, so that the lathe tool traveled in a 2-in. arc. Considerable difficulty was encountered in machining this laminated material because of its tendency to chip when cutting against the laminations. This difficulty was minimized by using high-cutting speeds and very sharp tools. All specimens were finished by sanding with No. 000 emery paper. The final strokes used in the sanding operation were made by hand, longitudinal to the specimen's axis. All specimens were prepared in a room which was maintained at a constant temperature of 77 ± 1 F., and a constant relative humidity of 50 ± 2 per cent, and were allowed to remain in this room for at least two weeks before the tests were started. All tests were performed in this room at the constant temperature and humidity indicated above, except those tests which were performed at high and low temperatures. These tests were run in a special cabinet as described below.

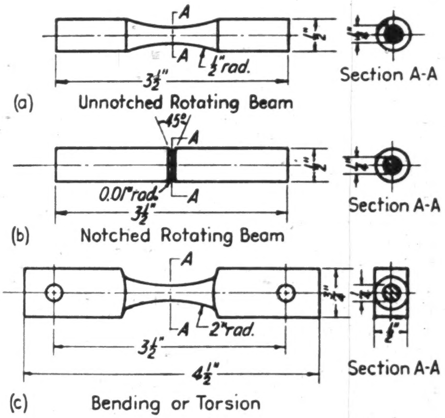

FIG. 1.—Specimens for Fatigue Tests.

DEFINITIONS

The term fatigue, as currently applied to behavior of engineering materials, refers to a condition brought about by a repeated deforming or loading of a member or specimen. The condition brought about by this repeated loading is a brittle cracking of the material, which develops more or less slowly and progresses as one or more cracks (or sometimes as a general fragmentation without well-defined cracks), which under many circumstances continues to spread until the member is completely fractured.

In order to measure the resistance of a material to failure by fatigue it is necessary to define some measurable quantity which will reflect this condition. One measure of the resistance to failure by fatigue is the well-known endurance limit—the maximum value of alternating stress below which the material will not fracture from fatigue for an indefinitely large number of cycles of stress (or deformation). It is applicable only for materials such as mild steel and cellulose acetate which exhibit the limiting value of stress just described. Other materials, such as aluminum alloys and plastics of the type under consideration, do not appear to have such a limiting value, at least such a limiting value of stress has not been demonstrated for these materials by tests lasting for 10^8 cycles. For such materials a different quantity must be used as a measure of their resistance to failure by fatigue. The quantity used in this paper, referred to as the *fatigue strength*, is defined[3] as the maximum amplitude of an alternating-stress cycle which will not cause fatigue failure of the material for a stated number of cycles of alternating stress. It is necessary to qualify further the fatigue strength by stating the value of the mean stress, in the stress cycle, together with the sign of the mean stress (tension, +, or compression, −). The mean stress may be defined as the algebraic average of the maximum stress and minimum stress in the stress cycle.

In cases in which the number of stress cycles occurring in the life of a part is much less than the number of cycles at which the endurance limit is reached, it may be desirable to use the fatigue strength at, say, 10^4 cycles, rather than the endurance limit when designing a part to be made of a material which has an endurance limit.

The above definition of fatigue strength has been based on, yet does not define, fatigue failure. When has a part failed by fatigue? At the time that a minute crack has just started, at the time when the member has become completely fractured, or at some intermediate stage? One may answer that fatigue failure has commenced with the start of the first crack, yet who has the patience or eyesight to detect an incipient crack. On the other hand, one might say that complete fracture is a satisfactory means of defining fatigue failure; however, in large-size members, members which last but a few cycles, or members made up of fibrous materials, the number of load cycles occurring between inception of the first crack and complete fracture of the part may be a very large proportion of the total number of cycles sustained, in which case complete frac-

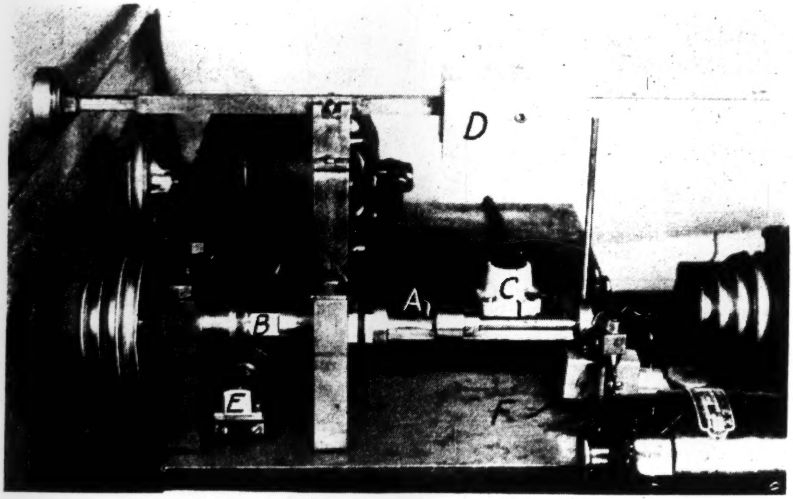

FIG. 2.—Rotating Cantilever-Beam Type Fatigue Testing Machine.

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[3] Tentative Method of Test for Repeated Flexural Stress (Fatigue) of Plastics (D 671 – 42 T), 1944 Book of A.S.T.M. Standards, Part III, p. 1638.

ture would hardly be a satisfactory definition of fatigue failure.

For the purposes of the present series of tests the author has elected to define fatigue failure as having occurred when a crack or cracks of a certain severity have developed. This, of course, is an arbitrary definition. The severity of crack selected for the above definition and the method of measurement used for the size of specimen and type of test employed in this program will be discussed for each type of apparatus.

ROTATING-CANTILEVER-BEAM FATIGUE TESTS

Machines:

The rotating-cantilever-beam fatigue tests were performed on machines such as shown in Fig. 2. These machines consisted of a motor-driven spindle *B*, to which the specimen *A* was attached co-axially by means of a split collet. A shaft extension *C* was fastened to the outer end of the specimen by means of a split collet machined integrally with the shaft. The entire assembly (spindle, specimen, and extension shaft) was rotated by a motor driving through a V-belt.

The specimen was bent downward by a load applied to the end of the extension shaft *C*. This load was produced by a beam and poise mechanism, *D*. The stress, σ, at the minimum section of the specimen was computed from the equation $\sigma = \frac{Mc}{I}$ in which the bending moment, M, was obtained from the load applied by the poise with suitable corrections for the moment produced by the extension shaft.

In order to determine the number of cycles to cause failure, a counter, *E*, was attached to record the number of cycles, and a microswitch, *F*, was used to stop the machine when a crack had started in the specimen. The microswitch was adjusted to shut the machine off when the fatigue crack had become

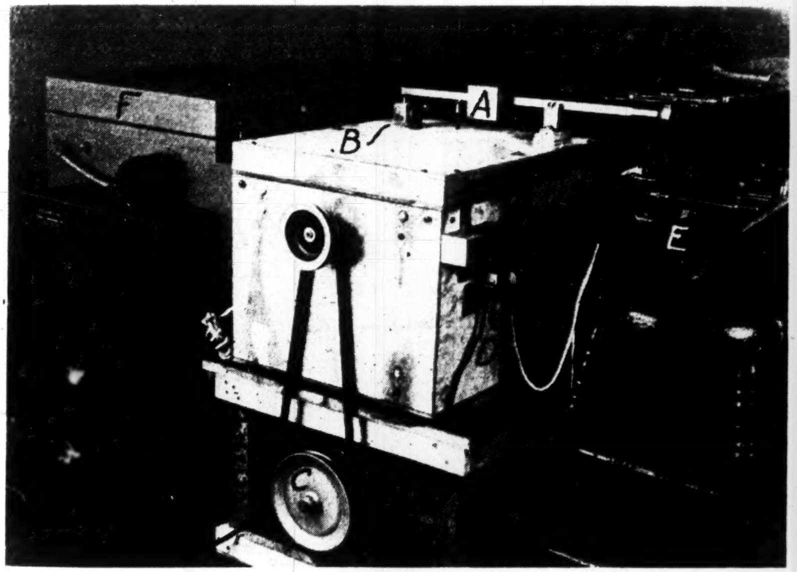

FIG. 3.—Rotating Cantilever-Beam Fatigue Machine Equipped with Apparatus for Controlling the Temperature over a Range from −75 F. to +400 F.

severe enough to cause the specimen to deflect 0.1 in. at the point of loading.

For fatigue tests to be conducted at temperatures above and below the temperature available in the air-conditioned testing room, an insulated box was constructed to house one of the rotating-cantilever-beam fatigue testing machines. The equipment used is shown in Fig. 3. The loading lever and poise *A*, microswitch *B*, motor *C*, and counter *D*, were mounted outside the insulated cabinet. For the high-temperature tests the box was heated by electric strip heaters, which were controlled by a thermostat adjustable from the outside of the cabinet. The air temperature in the cabinet and the specimens' temperatures were measured by means of a thermocouple and potentiometer, *E*. The specimens' temperatures were obtained by means of a thermocouple mounted on a lever which was moveable from the outside of the cabinet, and so positioned as to cause the thermocouple to touch the central portion of the specimen, when the lever was deflected. Temperature readings were taken by stopping the machine, applying the thermocouple to the surface of the specimens immediately, and recording the indicated temperature. The temperatures thus obtained were somewhat below the actual operating temperatures of the specimens because the specimen began to cool as soon as the machine was stopped.

When tests were to be run at temperatures below the testing room temperature, a separate insulated cabinet *F* was used to house dry ice, for use as a refrigerant. Air was circulated through the dry ice and the test cabinet and back again, to maintain the desired temperature. Thermostatic control was provided to manipulate the damper which controlled the flow of air through the dry ice. With this equipment it was

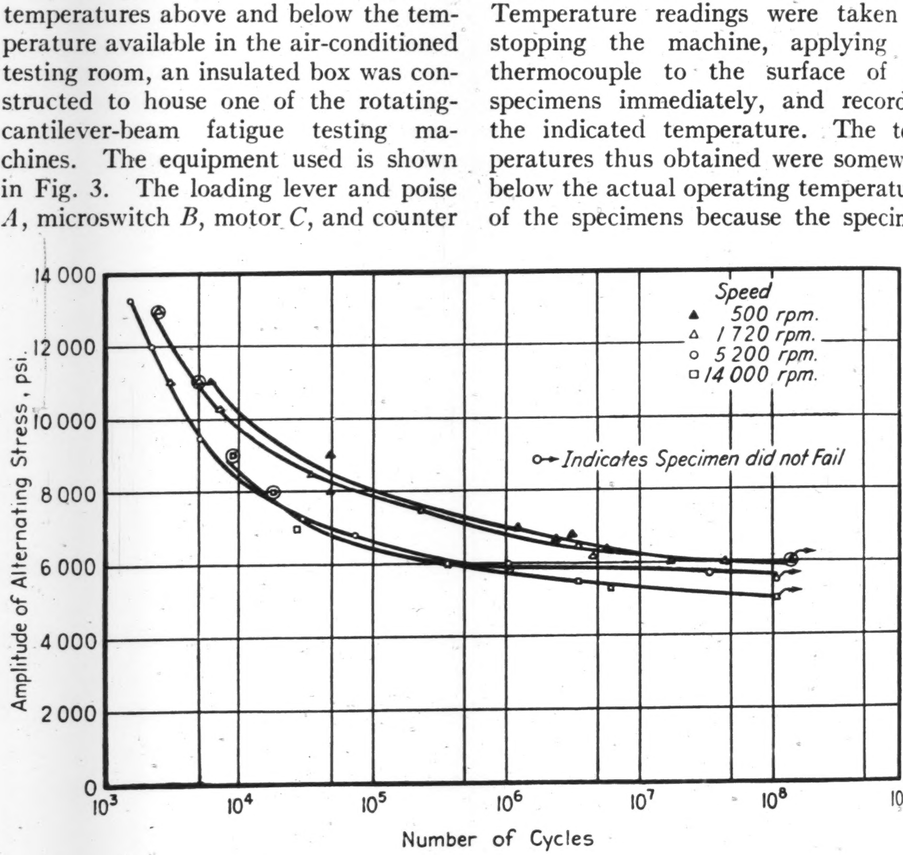

FIG. 4.—*S-N* Diagrams for Different Speeds of Testing with Unnotched Specimens, Fig. 1(*a*). Tests Were Conducted in a Room at 77 F. and 50 per cent Relative Humidity.

found possible to conduct continuous fatigue tests over periods of several days since the equipment required servicing only every 8 to 12 hr. In order to prevent ice from fouling the loading rod, which projected through the cabinet, a kerosine seal was used to prevent escape of cold air around the loading rod.

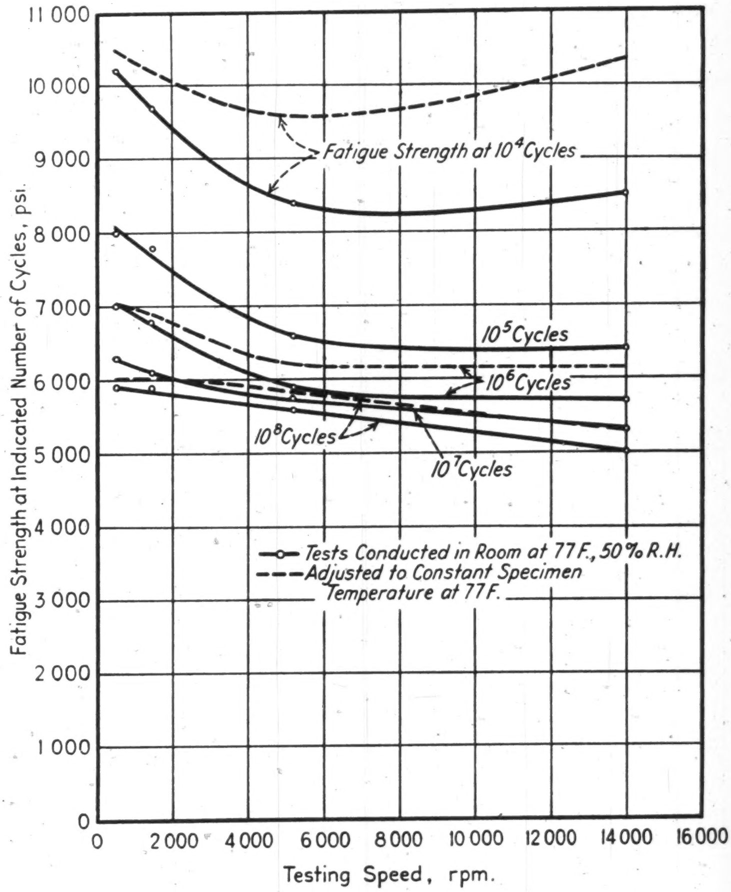

FIG. 5.—The Effect of Speed of Testing on the Fatigue Strength at 10^4, 10^5, 10^6, 10^7, and 10^8 Cycles. The Curves Adjusted to a Specimen Temperature of 77 F. Are Also Shown.

Effect of Speed of Testing:

Rotating-beam fatigue tests were performed at four different speeds of testing, ranging from 500 rpm. to 14,000 rpm. in order to determine the effect of speed on the results obtained from fatigue tests. The results of these tests are shown in Fig. 4. These data were plotted with the amplitude of the alternating stress as ordinate and the number of cycles for fatigue failure as abscissa, using semi-logarithmic plotting. The data shown in Fig. 4 were obtained from tests conducted at a temperature of 77 F. and a relative humidity of 50 per cent. The plotted points having circumscribed circles were plotted from data obtained with specimens machined about three months later than specimens used for the rest of the tests. Ageing, thus, may have influenced the results of these tests to some extent. It was observed that as the testing speed increased, the fatigue strength (that is, the ordinate) at a given number of cycles decreased. This effect is better illustrated in Fig. 5. In this figure the solid lines show the effect of testing speed on the fatigue strength measured at several different numbers of cycles. Figure 5 shows that in general the fatigue strength decreased as the speed of testing increased, irrespective of the number of cycles for which the fatigue strength was determined.

It was suspected that at least a portion of the effect produced by increasing testing speeds was caused by an increase in the temperature of the specimens, resulting from the heat generated by internal friction in the specimens, and also by another factor, which it was not found possible to control satisfactorily, namely, the heat generated by the ball bearings of the fatigue testing machine.

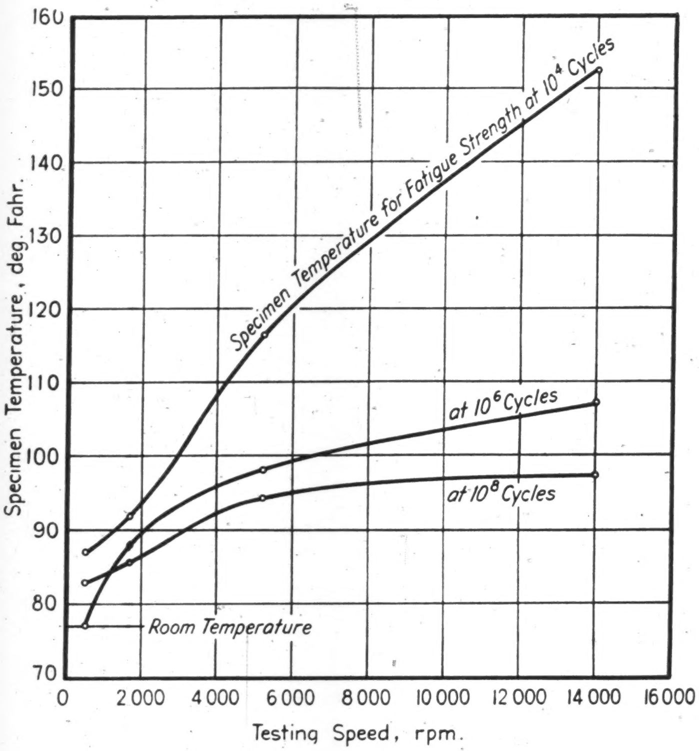

FIG. 6.—The Effect of Speed of Testing on the Specimen Temperature of Unnotched Specimens for Stresses Corresponding to the Fatigue Strength at 10^4, 10^6, and 10^8 Cycles.

In order to separate the effect of small variations in specimen temperature from the effect of testing speed, the temperatures developed in specimens operating at various speeds and amplitudes of stress were determined. The data obtained are presented in Fig. 6, in which the temperature resulting from the operation of a specimen at a given speed of testing and an amplitude of stress, which would cause failure at a given

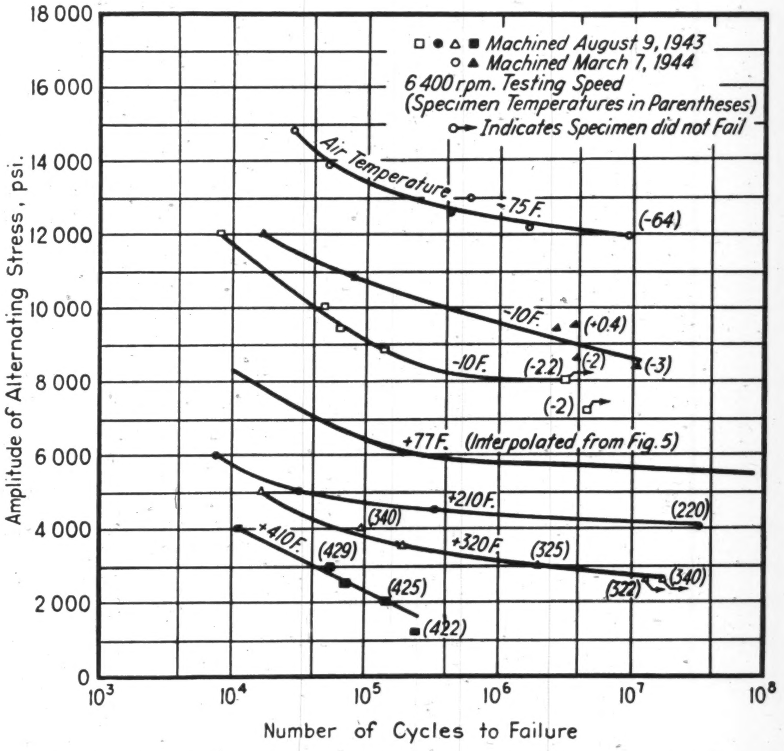

FIG. 7.—*S-N* Diagrams for Rotating-Beam Fatigue Tests at Temperatures from −75 to +410 F. The Speed of Testing Used in These Tests was 6400 rpm., and the Specimens Were Unnotched.

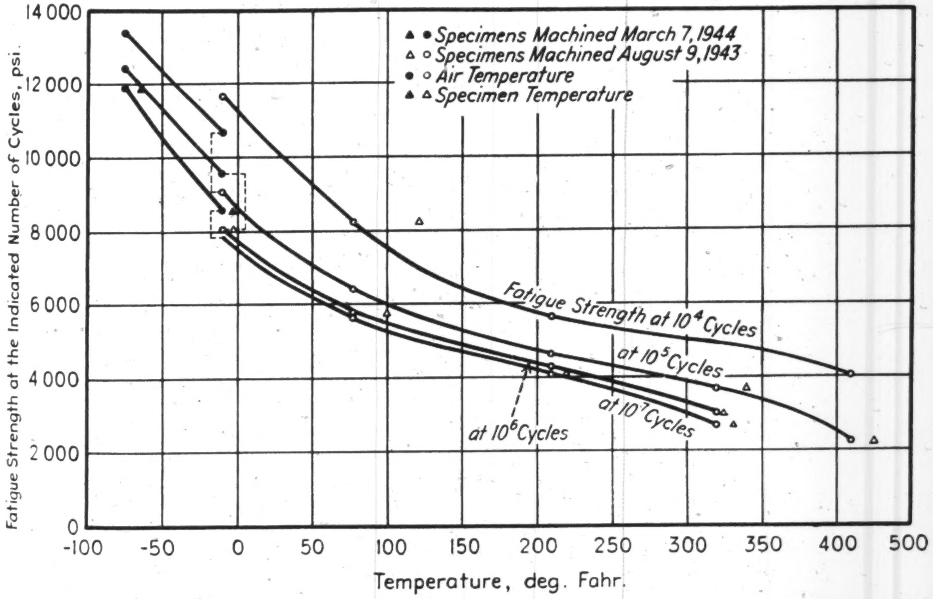

FIG. 8.—The Effect of Temperature on the Fatigue Strength at 10^4, 10^5, 10^6, and 10^7 Cycles. The Speed of Testing Used in These Tests was 6400 rpm., and the Specimens Were Unnotched.

number of cycles, is plotted as ordinate against the speed of testing as abscissa. Three curves are shown: one for stresses which would produce failure after 10^4 cycles, another 10^6 cycles, and a third at 10^8 cycles. It was observed that the specimen temperature increased both with increase in testing speed and increase in amplitude of alternating stress. The temperatures were measured after the specimens had been in operation for about 20 min. in the case of the lower two curves, and after the specimens had been in operation for about 5 min. in the case of the upper curve. Subsequent tests on other materials have shown that specimens operating at stresses which will cause failure after 10^8 cycles reach an equilibrium value of temperature within about 20 min., after which the temperature remains constant for a long period. The temperatures shown in Fig. 6 were used in conjunction with another series of tests, described below, in which the effect of temperature upon the fatigue strength was determined, to correct the effect-of-speed data (Fig. 5) for variations of specimen temperature. The dash lines shown in Fig. 5 represent the fatigue strengths adjusted to a common specimen temperature of 77 F. The adjusted curves show that the fatigue strength at 10^6 and 10^8 cycles decreased as the speed of testing increased, but the effect was not as great as indicated before the data had been adjusted to a common temperature. The adjusted data indicate that the fatigue strength at 10^4 cycles decreased at first and then increased to approximately its former value as the speed was increased from 500 rpm. to 14,000 rpm.

The adjusted curves for the effect of testing speed, shown by dash lines in Fig. 5, were obtained by interpolating from the fatigue strength at the measured temperatures at which the tests were run (Fig. 6) to the fatigue strength at 77 F. in accordance with the trend shown in Fig. 8 for the effect of temperature on the fatigue strength.

Effect of Temperature:

Rotating-beam type fatigue tests were run at a variety of temperatures, using the apparatus described above, and shown in Fig. 3. The temperatures employed ranged from −75 F. to +410 F. The *S-N* diagrams for these tests are shown in Fig. 7. The data show that as the temperature was increased the fatigue strength decreased.

A comparison of the two curves at −10 F. indicates that specimens tested at nearly the same time but machined seven months apart yield widely different results. The length of time that a freshly machined specimen was exposed to a temperature of 77 F. and 50 per cent relative humidity caused the fatigue strength of this material to be lower for specimens machined 7 months before testing than for specimens machined 2 weeks before testing. The difference may be caused by a gradual evaporation of moisture or of other volatile materials.

The temperature developed in the specimens ranged from 2 to 20 deg. above the temperature of the surrounding air for specimens in which the temperature was measured. The specimen temperatures are shown in parenthesis adjacent to the plotted points in Fig. 7.

The effect of the temperature of the surrounding air on the fatigue strength at 10^4, 10^5, 10^6, and 10^7 cycles is illustrated in Fig. 8. It was observed that as the temperature was increased from −75 F. the fatigue strength decreased rather rapidly, and then less rapidly until a temperature of approximately 320 F. was reached. At a temperature of 410 F., the effect of the temperature was such as to make the length of exposure to the high temperature of more significance than the number of stress cycles sustained. The temperatures of the specimens are also shown in Fig. 8 for cases in which specimen temperatures were measured. The plotted points corresponding to specimen temperatures are shown on Fig. 8 by triangles. The offset in the curves of Fig. 8 occurring at −10 F. was caused by a change to specimens of a different age, as described above.

It should be mentioned that before the tests were started all specimens tested in this series were allowed to remain at the test temperature for ½ hr. after the temperature of the air in the test cabinet had reached the desired value.

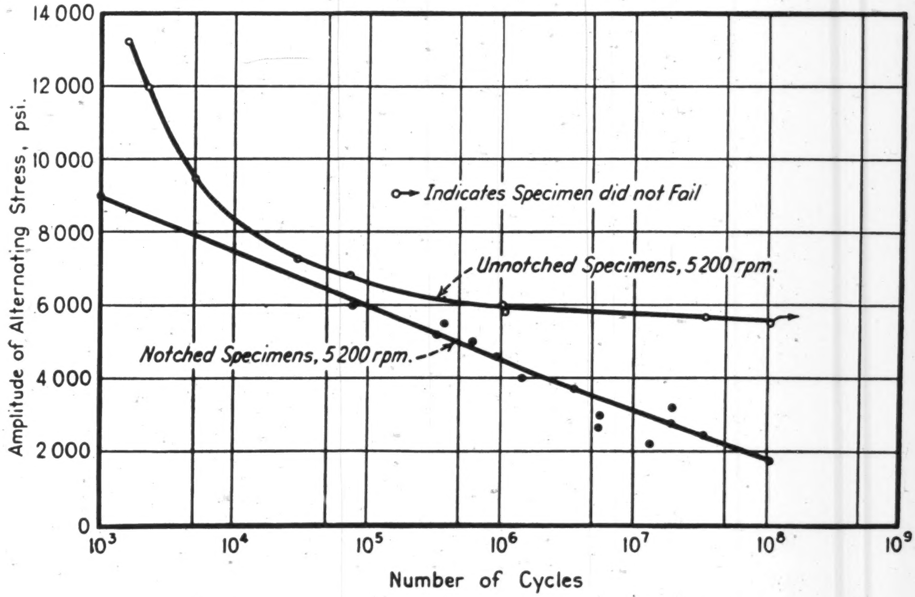

FIG. 9.—*S-N* Diagram for Rotating-Beam Fatigue Tests of Notched and Unnotched Specimens Tested at a Speed of 5200 rpm.

Elevated temperatures affected the test specimens in several ways. Exposure to the elevated temperature caused a progressive deterioration, which was evidenced by a gradual charring, accompanied by embrittlement of the material. The deterioration of the material was noticeable at 320 F. but was very marked at 410 F. In addition to this deterioration, a decrease in fatigue strength, as noted above, resulted from an increase in temperature. That is, the fatigue strength properties of the material were affected by changes in temperature, even at temperatures at which no deterioration resulted from exposure to the temperature. A decrease in stiffness (modulus of elasticity) also resulted from an increase in temperature. This phenomenon was observed by the smaller deflection under load at low temperatures, as compared to the deflection under the same load at elevated temperatures. There was also a noticeable thermal expansion with increase in temperature, which caused the specimens to loosen in the collets at the low temperatures. Excessive expansion at the high temperatures caused some difficulty, due to the restraining action of the collet. The resulting differential expansion between the restrained portions and unrestrained portions of the specimen caused a splitting to occur.

Effect of a Deep Notch:

The effect of a deep notch on the fatigue strength of this material was studied by testing specimens, such as shown in Fig. 1(*b*), in rotating-cantilever-beam fatigue testing machines. The *S-N* diagram plotted from the data is shown in Fig. 9, together with the corresponding *S-N* diagram for tests of unnotched specimens at the same testing speed of 5200 rpm. The stresses calculated for the notched specimens were the nominal stresses obtained from the equation $\sigma = \frac{Mc}{I}$, and were based on the diameter at the root of the notch. The shape of the two *S-N* diagrams is markedly different. The *S-N* diagram for the notched specimens shows no indication of leveling off, as the amplitude of the alternating stress was decreased. The fatigue strength at 10^5 cycles was nearly the same for both notched and unnotched specimens, but the fatigue strength at a smaller number of cycles and also at a larger number of cycles was much less for the notched specimens than the unnotched specimens. At 10^8 cycles the fatigue strength of notched specimens was approximately one third that of unnotched specimens. This difference in behavior may have been the result of one or several of the following factors: In the unnotched specimens the state of stress was a uniaxial tensile stress at the surface of the specimens, whereas in the deep notched specimens the state of stress in a region slightly below the surface of the notch approached a state of triaxial tensile stress. Also there was a stress concentration caused by the presence of the notch, which while less severe than in the case of a shallow notch, was still a significant stress concentration. Another factor, which may have been significant, was the fact that there was a large volume of low-stress material immediately adjacent to the high-stress material in the notched specimens, so that the heat developed from hysteresis damping in the material of the notch, may have been more readily dissipated than heat developed from an equal stress in the unnotched specimens. Thus, the temperature developed in the notched specimens may have been nearer room temperature than that developed in the unnotched specimens for the same actual value of stress. The lower temperature, however, would tend to increase the fatigue strength as shown above and thus tend to counteract the effect of the stress concentration. Because of the considerations enumerated above it would not seem appropriate to label the ratio of the fatigue strength of the unnotched specimens to the fatigue strength of the notched specimens, "the stress concentration factor."

CONSTANT AMPLITUDE-OF-DEFLECTION FATIGUE TESTS

Machines Arranged for Bending Fatigue:

One of the constant amplitude-of-deflection fatigue machines arranged for bending fatigue tests is shown in Fig. 10. In this fatigue machine the specimen, *B*, was fastened to a dynamometer, *C*, at one end. The other end of the specimen was bolted to a moment arm *E*. This moment arm was caused to be moved up and down in a vertical plane by a connecting rod, *F*. An adjustable eccentric *G* was used to obtain the amplitude of the alternating deflection desired, and the deflection of the dynamometer *C* was measured by means of dial *D*.

The testing procedure described in the A.S.T.M. Tentative Method D 671[3] was used for the tests reported in this section, with certain modifications. The specimens used for the bending fatigue tests, and also the torsion fatigue tests which will be described later, were turned to the dimensions shown in Fig. 1(*c*). The

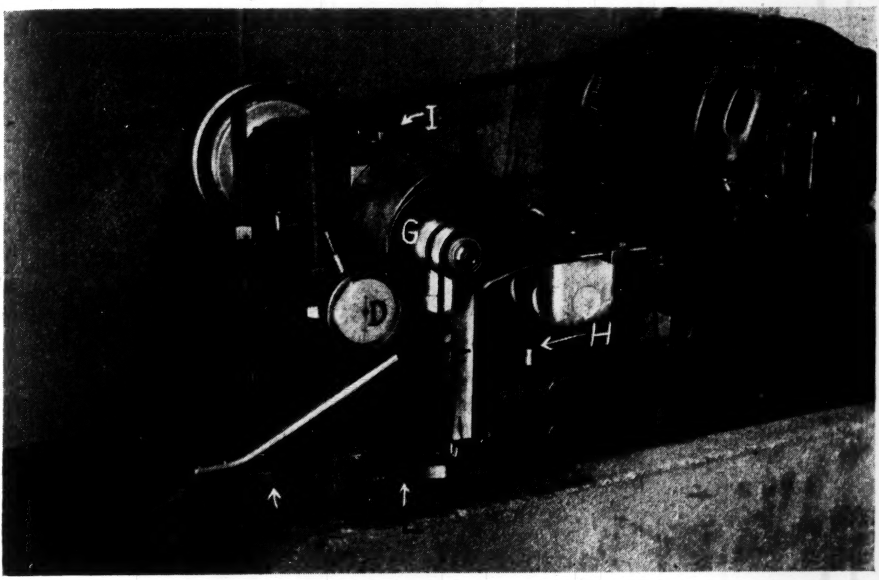

FIG. 10.—Constant Amplitude-of-Deflection Type Fatigue Machine Arranged for Tests in Bending.

FIG. 11.—Constant Amplitude-of-Deflection Type Fatigue Machine Arranged for Tests in Torsion.

amplitude of the alternating stress was computed from the equation $\sigma = \frac{Mc}{I}$, in which the bending moment, *M*, was obtained from readings of the calibrated dynamometer *C*. The number of cycles to which the specimen was subjected was indicated by a counter *I*.

The stress values to which each specimen was subjected at the beginning of the test were calculated from the bending moments measured by means of the dynamometer while the machine was at rest; and the number of cycles for fatigue failure was determined in the manner described below. These data were then plotted as *S-N* diagrams with the amplitude of the alternating stress as ordinate and the number of cycles for failure as abscissa.

Machines Arranged for Torsion Fatigue:

The machines used for torsion fatigue tests were of the same type as used for the bending fatigue tests, and were constructed by the addition of certain parts, as shown in Fig. 11. An arm *A* was attached to the machine so as to support the fixed end of the torsion specimen *B* and the dynamometer *C* with its dial *D*. For the torsion test the specimen *B* was fastened at an angle to the torque arm *E*, which was attached to the connecting rod *F* through a universal joint. The angle between the axis of the specimen and the torque arm was so chosen that the bending moment at the minimum section of the specimen was zero, and the only significant stresses at the minimum section were shearing stresses, due to torsion. There was, however, a horizontal shearing stress whose magnitude was negligible compared to the stresses resulting from torsion.

The dynamometer *C* was calibrated in terms of torque *T* and the shearing stresses τ were computed from the equation $\tau = \frac{Tc}{J}$. The stress was adjusted by means of the adjustable eccentric, *G*, and the test was conducted in the same manner as in the bending fatigue test.

For both tests, the range of stress, that is, the relationship between the maximum stress and the minimum stress in a stress cycle, was adjusted by means of a mechanism, one form of which, consisting of screws, *H*, for tilting the bracket to which the specimen and dynamometer were attached, is shown in Figs. 10 and 11.

Load-Deflection Relationship:

With the laminated paper plastic tested, as with most, if not all, molded and laminated plastics containing fibrous fillers, it is difficult to detect fatigue failures, under the conditions imposed by this test method. The specimen did not completely fracture except for very high alternating stresses. Instead it was found that the fatigue crack formed and spread rapidly at first, but then reached a point at which the rate of growth was very slow. Also it was observed that the rate of growth of fatigue cracks varied from specimen to specimen. Thus, a means other than complete fracture of the specimen had to be devised which would detect fatigue failure in the relatively early stages.

As a solution it was decided to define fatigue failure arbitrarily as having occurred when fatigue cracks of a given severity had developed in a specimen. It was further decided that for specimens of the size under consideration the severity of cracks which would be considered to constitute fatigue failure would be arbitrarily defined as those producing a decrease in stiffness of the specimens to seven eighths of the initial stiffness.

For either bending or torsion fatigue tests involving *completely reversed* stress cycles this definition offered no difficulty. It was only necessary to measure and record the change in the maximum values of the dynamometer readings at intervals throughout the life of the test until the required change in the dynamometer readings was observed. However, for tests in which the stress cycle was not completely reversed, measuring the change in stiffness was somewhat more involved, since a change in the maximum or minimum load was no longer a reasonably close approximation to the corresponding change in stiffness. This was due to the fact that either the formation of a crack in a specimen or relaxation of the specimen due to creep resulted in a redistribution of internal stress in the specimen, so that the load-deflection curve no longer passed through the origin. This action is outlined in the diagram inset in Fig. 12, in which the load-deflection diagram of an uncracked specimen is approximated by curve *aob*. If relaxation took place but there was no effect from fatigue, then the load-deflection curve of the specimen after a period of time would be represented by curves *cde*. If, on the other hand, a fatigue crack developed, the crack would open when the specimen was bent in one direction, but would tend to close when the specimen was bent in the opposite direction. Thus the stiffness would be unchanged when the specimen was bent in such a way as to keep the crack closed, but the stiffness would be decreased when the specimen was bent in such a direction as to cause the crack

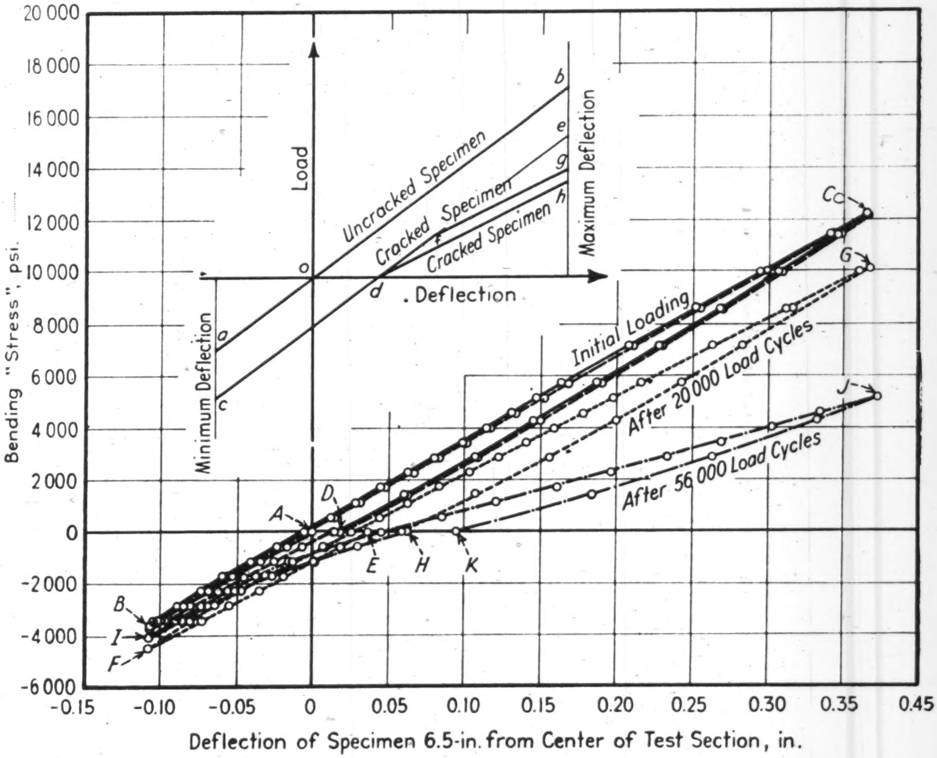

FIG. 12.—Load-Deflection Curves of a Specimen in Bending Taken Prior to and During a Fatigue Test.

to open. This action would result in a load-deflection curve similar to that shown by curve *cdh*, if the deflection at which the crack closed was at *d*, but a curve such as *cdfg*, might be expected if the closing of the crack did not occur at zero load because of residual stresses, or fragmentation, or deformation in the region of the crack.

According to the definition of fatigue failure given above fatigue failure occured when the portion of the curve from *f* to *g* or *d* to *h* had a slope equal to seven eighths of the slope of the curve *aob* of the uncracked specimen.

The slope of the curve can be determined by noting the value of the load at two known values of deflection, such as, for example, the maximum deflection and some other point along the curve from *f* to *g*. If, however, the load cycle was such that the loading was always either up or down, then readings of the maximum and minimum load could be used to determine the slope of the load-deflection curve since a fatigue crack could be expected to remain open during the entire load cycle. The latter technique was used for all tests reported except the tests for which the mean stress was zero.

In order to determine how the material under study actually behaved in a fatigue test in which the maximum load and minimum load were unequal and of opposite sign, a load-deflection curve was obtained for the first loading cycle of a specimen and was repeated at intervals thereafter. The load-deflection readings were obtained under static conditions. The initial value of the maximum stress to which the specimen was subjected in the load-deflection test was 12,200 psi., and the minimum stress was −3600 psi., or expressing this cycle of stress in terms of a mean stress and a superimposed alternating stress the mean stress becomes 4300 psi., and the amplitude of the alternating stress becomes 7900 psi.

The results of the load-deflection measurements are shown in the lower group of curves in Fig. 12. In this figure loads have been converted to nominal stress values for convenience in interpretation. The first load cycle which the specimen sustained is shown by the curve drawn as a solid line from *A* to *B*, *C*, and *D*. The next cycle is shown by the long dash lines starting from *D* to *B*, and from this point paralleling the original curve from *B* to *A*, *C*, and *D*. A hysteresis loop was indicated by the fact that the loading branch and unloading branch of the curve did not coincide. The size of the hysteresis loop in this test was probably augmented by relaxation taking place during the time of the test.

After the initial load cycles were obtained, the fatigue machine was started and run for a few cycles, then a load-deflection curve was again obtained. This procedure was repeated for three different intervals. The load-deflection curves for two of these periods are shown in Fig. 12. A curve obtained after 20,000 cycles of loading is shown by the short-dash line starting at *E* to *F* to *G*, and back to *H*. It was observed that a fatigue crack had formed in the specimen at the time that these readings were taken. An examination of the curve *EFGH* shows that the loading branch of the curve is similar to the hypothetical curve *cdfg* (shown in the upper diagram Fig. 12) except that the change in slope of the curve is not abrupt as at *f* and occurs below the zero load line, rather than above the line. The slope of the upper branch of the curve from *F* to *G* is 90 per cent of the slope of the corresponding branch of the initial curve (or slightly more than seven eighths of the initial slope). The slope of a straight line joining points *F* and *G*, on the other hand, is 92 per cent of the slope of the

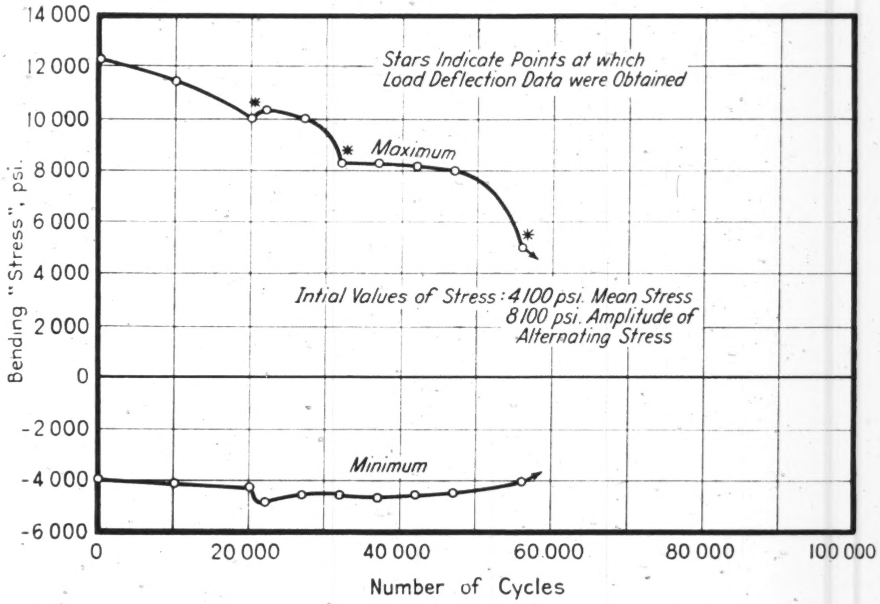

FIG. 13.—The Effect of the Number of Cycles of Deflection on the Maximum and Minimum Values of the Nominal Stress for a Fatigue Test in which Failure Occurred after a Small Number of Cycles. (Figures 12 and 13 were Prepared from the Same Test.)

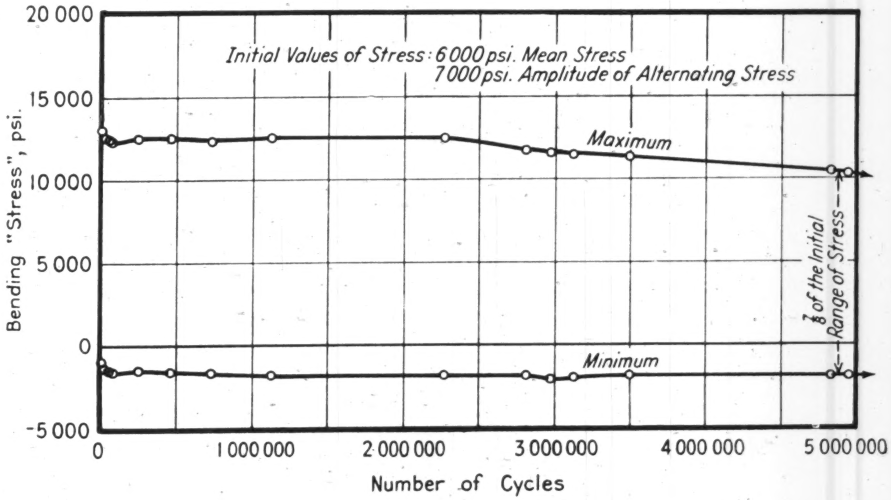

FIG. 14.—The Effect of the Number of Cycles of Deflection on the Maximum and Minimum Values of the Nominal Stress for a Fatigue Test in Which Failure Occurred after a Large Number of Cycles.

straight line joining points *B* and *C*. Inasmuch as the difference between slopes measured in these two manners is so small, and the latter method required the determination of only the maximum and minimum loads rather than the complete loading curve, the latter method has been used for all tests reported in this paper except for zero mean stress. The error involved is probably small for all cases considered, but may be somewhat larger than the error just indicated for cases in which the mean stress is more nearly zero.

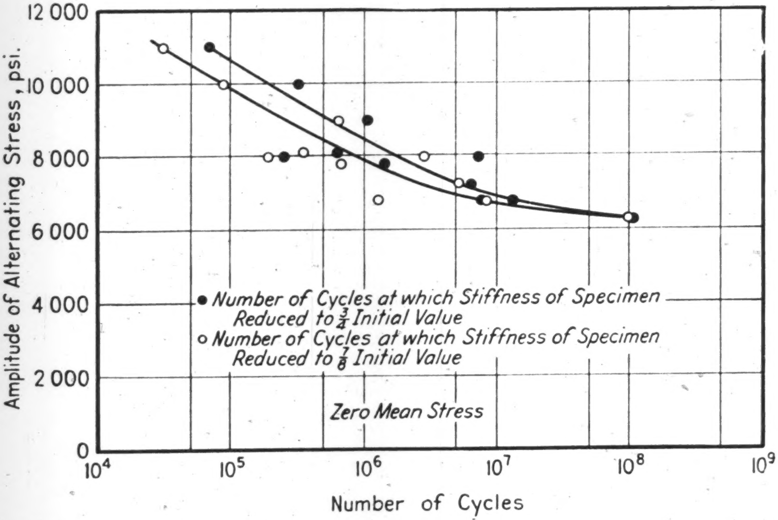

FIG. 15.—*S-N* Diagram for Completely Reversed Fatigue Tests in Bending, Showing the Effect of Two Different Definitions of Failure on the Interpretation of Test Results.

The load-deflection curve obtained after the specimen had been subjected to 56,000 load cycles is also shown in Fig. 12. After this number of cycles the specimen had developed cracks on both sides. The curve extends from *H* to *I*, *J* and *K*. It was observed that the stiffness, as measured by the slope of the load-deflection curve, was markedly decreased at this value of cycles, and that the negative branch of the curve was now markedly bent downward in the lower region compared to the upper region. It was also observed that the magnitude of the minimum deflection was now less than it was after 20,000 loading cycles. This reversal in the trend was probably due to the formation of the fatigue cracks on the opposite side of the specimen.

A plot showing the variation of maximum and minimum stresses, with number of cycles sustained, is shown in Fig. 13. It was observed that for the range of stress shown the maximum stress decreased with increase in the number of cycles, and the minimum stress increased in numerical value with increase in number of cycles. The effect of stopping the tests long enough to obtain load-deflection diagrams is indicated by the discontinuities shown at the stars in Fig. 13. These discontinuities may be largely due to a decrease in temperature, during the stopped period, which would result in an increase in stiffness.

The stress values shown in Figs. 12 and 13 as ordinates should not be considered to be true values of stress for all conditions, inasmuch as the formation of a crack in the specimen caused a redistribution of stress which made it impossible to determine the significant stress occurring in the notch formed by the fatigue crack.

If fatigue failure be defined as indicated above, as occurring when the stiffness of a specimen has been reduced to seven eighths of its initial value, and the change in stiffness be measured by the change in the range of stress (for tests other than complete reversal), then failure was indicated for the test shown in Fig. 13 at about 30,000 cycles.

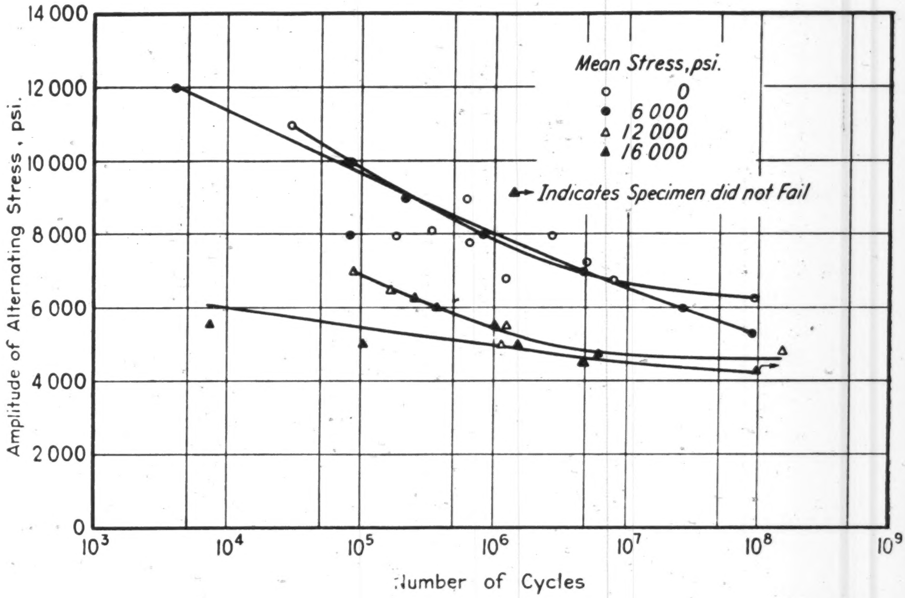

FIG. 16.—*S-N* Diagrams for Fatigue Tests in Bending at Several Different Values of Mean Stress

The change in maximum and minimum stress, with number of cycles, is shown in Fig. 14 for another specimen for which failure was indicated at about 5,000,000 cycles. This test shows a rapid relaxation at the beginning of the test, then substantially no change in the stresses for 2,500,000 cycles, followed by a gradual decrease in the maximum stress.

Effect of Definition of Failure on the Interpretation of Results:

Two *S-N* diagrams for a series of fatigue tests in bending are shown in Fig. 15 for specimens tested in a completely reversed stress cycle, that is a range of stress in which the mean stress was zero. Figure 15 shows the effect of changing the definition of failure from a reduction in stiffness to seven eighths of the initial value to a reduction in stiffness to three fourths of the initial value. It was observed that the change in definition made very little difference in the fatigue strength of the material at a large number of cycles, but at 10^5 cycles the indicated fatigue strength for failure defined in terms of a change in stiffness to seven eighths of the initial value was about 8 per cent lower than it was when defined in terms of a change in stiffness to three fourths of the initial value of stiffness.

Effect of Mean Stress on the Fatigue Strength for Tests in Bending:

Fatigue tests of specimens of the shape shown in Fig. 1(*c*) were performed at four different ranges of stress, for which the mean values of stress were 0, 6000, 12,000, and 16,000 psi. The *S-N* diagrams for these tests are shown in Fig. 16. For the tests at zero mean stress, failure was defined as having taken place when the maximum stress (for bending in either direction) had decreased to seven eighths of the initial value. For all other tests failure was defined as having taken place when the range of stress, that is, the maximum stress minus the minimum stress, had decreased to seven eighths of the initial value of the range of stress. In Fig. 16 the amplitude of the alternating-stress cycle is plotted as ordinate against the number of cycles to failure (defined above) as abscissa. The *S-N* diagrams shown indicate that the magnitude of the fatigue strength (the amplitude of the alternating-stress cycle) at any given number of cycles decreases as the mean stress increases. This behavior is shown in Fig. 17, in which the amplitude of the alternating-stress cycle is plotted as a function of the mean stress for three different values of the numbers of cycles at which fatigue failure occurred. In other words, the fatigue strength at 10^5, 10^7, and 10^8 cycles is plotted as a function of mean stress. In general the fatigue strength decreased as the mean stress was increased.

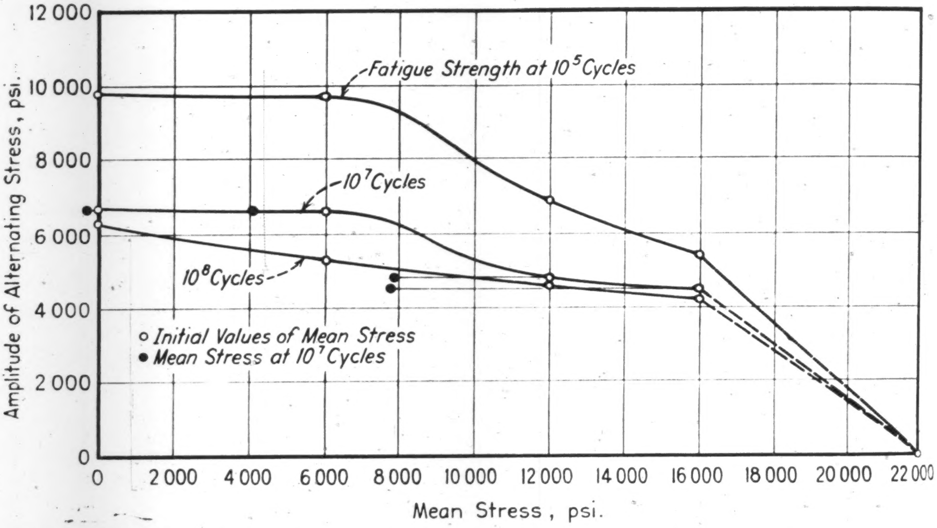

FIG. 17.—The Effect of Mean Stress on the Fatigue Strength at Several Different Numbers of Cycles for Tests in Bending.

The plotted point on the horizontal axis represents the modulus of rupture of a specimen of the same shape as used in a fatigue test, but tested in static bending (see Table II). Four-point loading was used in the test from which this modulus of rupture was obtained, and the rate of strain used was substantially the same as that used for the tension tests of this same material, reported in a previous paper (1). The rate of strain used was 0.0013 in. per inch per min. and was determined by plotting a load-time curve, determining the rate of loading, and converting to rate of strain by means of the modulus of elasticity.

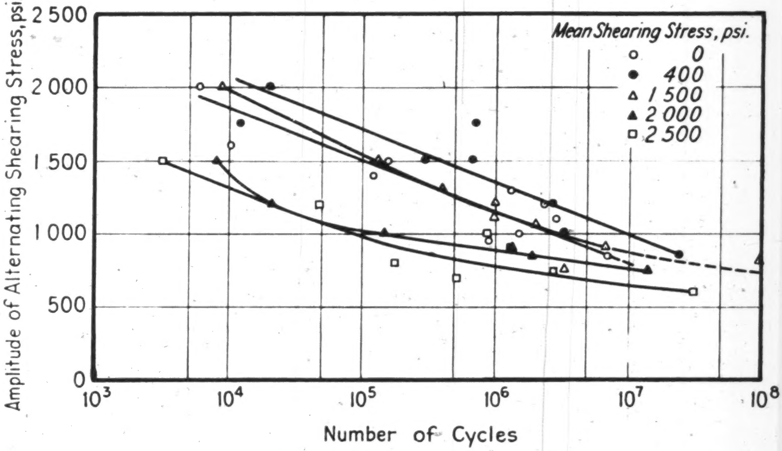

FIG. 18.—*S-N* Diagrams for Fatigue Tests in Torsion at Several Different Values of Mean Stress.

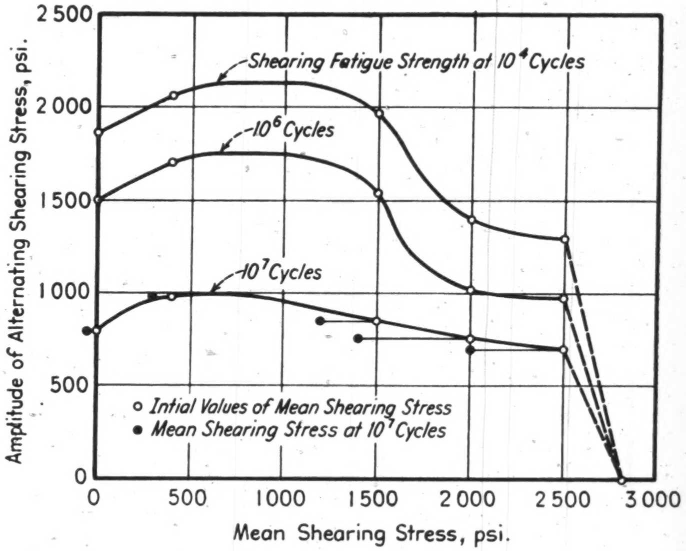

FIG. 19.—The Effect of Mean Shearing Stress on the Fatigue Strength in Shear at Several Different Numbers of Cycles for Tests in Torsion.

The modulus of rupture plotted in Fig. 17 does not seem to agree any too well with the fatigue test data. If, as seems reasonable, the modulus of rupture should lie on the same curve with the fatigue data in Fig. 17, it would appear that the modulus of rupture should have been considerably higher. This apparent discrepancy may have been caused in part by the wide difference in rate of strain occurring in the fatigue test as compared to the static bending test. Another contributing factor may be the fact that the mean stress in all cases changed gradually during the conduct of the fatigue test. The magnitude of the change is illustrated in Fig. 17 by the solid circles which represent the values of mean stress occurring after tests operating at the indicated amplitude of alternating stress had been subjected to 10^7 cycles of stress. For the cases shown, the change in mean stress was largely due to relaxation, although the change was partly caused by the development of fatigue cracks in tests involving high alternating stresses.

Effect of Mean Stress on the Fatigue Strength for Tests in Torsion:

Torsion fatigue tests are of particular interest in tests of laminated materials because the torsion test permits study of the shearing fatigue strength of the bond between laminations.

Specimens of the type shown in Fig. 1(*c*) were tested in torsion fatigue at five different ranges of shearing stress. The mean values of the shearing stress used in these five series of tests were: 0, 400, 1500, 2000, and 2500 psi. The *S-N* diagrams for these tests are shown in Fig. 18. The means of detecting fatigue failure and the definition of fatigue failure used for the torsion fatigue tests were identical to those used for the bending fatigue tests described in the preceding section. As in the case of the bending fatigue tests, the amplitude of the alternating stress cycle was plotted as ordinate against the number of cycles to failure (defined above) as abscissa. This scatter observed in these tests may have been partly the result of variations in the degree of bonding between laminations for different specimens.

The effect of mean stress on the fatigue strength in torsion is shown in Fig. 19 which indicates that the fatigue strength increases slightly with increase in mean shearing stress, then decreases to somewhat below the initial value for fatigue strength at 10^7 cycles, but decreases considerably more for fatigue strengths at 10^4 cycles and 10^6 cycles. In view of the amount of scatter in the data shown in Fig. 18, the trend in Fig. 19 cannot be considered to be fully established, but the data indicate that in general the fatigue strength in torsion decreases with increase in the value of the mean shearing stress.

The plotted point on the horizontal axis represents the modulus of rupture in torsion as obtained from tests reported in a previous paper (1) (see Table II). As in the case of the bending fatigue tests, the modulus of rupture in torsion plotted in Fig. 19 does not seem to agree very well with the fatigue test data. The apparent discrepancy may have been the result of the wide difference in rate of strain between tests under fatigue conditions, as compared to tests under static conditions. And as in the case of the fatigue tests in bending, another contributing factor may have been the fact that the mean shearing stress in all cases changed during the conduct of the fatigue test. The magnitude of the change in mean shearing stress is illustrated in Fig. 19 by the solid circles, which represent the value of the mean stress which existed after the specimen operating at the indicated amplitude of alternating stress had been subjected to 10^7 cycles of alternating shearing stress. The change in mean shearing stress was probably due to the same factors which were discussed above in connection with the bending fatigue tests.

Effect of Temperature:

The temperature developed in specimens tested in torsion was determined by fastening the bead of a thermocouple to the center of the test section of a specimen by means of a small piece of cellulose tape. Temperatures were obtained for several stress values at the operating speed of 1720 rpm. The temperatures were observed to vary from 83.6 F. at an amplitude of alternating shearing stress of 900 psi. to 92.3 F. at an amplitude of 1750 psi. For all types of tests reported in this paper at all temperatures tested the temperature of the specimen was observed to rise from 5 to 10 F. above the surrounding air temperature, when the specimen was operating at a stress corresponding to the fatigue strength at 10^7 cycles. As mentioned previously, this rise in temperature was, in most cases, due entirely to hysteresis damping in the specimen.

TABLE I.—SUMMARY OF FATIGUE TEST DATA.
Axis of all specimens parallel to the grain of the paper in the laminate.

Type of Machine	Type of Specimen	Fatigue Strength at given Number of Cycles, psi.	Number Cycles to Failure	Initial Value of Mean Stress, psi.	Value of Mean Stress at 10^7 Cycles, psi.	Testing Speed, rpm.	Air Temperature, deg. Fahr.
Rotating cantilever beam machine:							
Fig. 2	Unnotched specimens Fig. 1(*a*)	6300	10^7	0	0	500	77
		6200	10^7	0	0	1720	77
		5800	10^7	0	0	5200	77
		5300	10^7	0	0	14000	77
	Notched specimens Fig. 1(*b*)	3100	10^7	0	0	5200	77
Fig. 3	Unnotched specimens Fig. 1(*a*)	2300	10^5	0	0	6400	410
		2800	10^7	0	0	6400	320
		4200	10^7	0	0	6400	210
		8600	10^7	0	0	6400	−10
		11900	10^7	0	0	6400	−75
Constant amplitude of deflection machine:							
(Bending) Fig. 10	Unnotched specimen Fig. 1(*c*)	6700	10^7	0	250	1720	77
		6600	10^7	6000	4100	1720	77
		4800	10^7	12000	7900	1720	77
		4500	10^7	16000	7800	1720	77
(Torsion) Fig. 11	Unnotched specimen Fig. 1(*c*)	790	10^7	0	40	1720	77
		980	10^7	400	300	1720	77
		850	10^7	1500	1200	1720	77
		760	10^7	2000	1400	1720	77
		650	10^7	2500	2000	1720	77

The rise in temperature affected the tests conducted on the constant amplitude-of-deflection fatigue machine in a somewhat different manner than the rise in temperature affected the tests on the rotating-cantilever-beam fatigue machine. It has been observed by other investigators (**14**, pp. 25 and 26) that the modulus of elasticity of plastics changes with temperature. Thus, a small increase in temperature resulting from hysteresis damping, as mentioned above, results in a decrease in the modulus of elasticity (or stiffness) of the material. This decrease in stiffness of the specimen results in a decrease in the mean load and the amplitude of the alternating load applied to the specimen. Because of the small increase in specimen temperature at a moderate amplitude of alternating stress, the change in load resulting from the increase in specimen temperature was small for tests which were operating at stresses near the fatigue strength at 10^7 cycles. The effect was more pronounced, however, at high stresses, where a large increase in specimen temperature was observed. According to the available data on the effect of temperature on the modulus of elasticity of laminated plastics (**10**), the effect of temperature on the stress values for specimens operating at the fatigue strength at 10^7 cycles would be to cause a decrease in stresses of 3 to 5 per cent from the values calculated under static conditions. All stress values reported in the fatigue tests were, however, the stresses which obtained at the beginning of the tests.

RESULTS AND CONCLUSIONS

The results of fatigue tests of a laminated high-strength paper plastic are summarized in Table I; in this table the fatigue strengths under a variety of different conditions are given, together with the pertinent data on the different conditions studied. A summary of the mechanical properties of this laminate under static test conditions is given in Table II.

TABLE II.—SUMMARY OF STATIC TEST DATA.
All specimens tested at 77 F., 50 per cent relative humidity and rate of tensile strain of 0.0015 per min.

Test	Modulus of Elasticity, psi.	Yield Strength, 0.2 per cent offset, psi.	Ultimate Strength or Modulus of Rupture, psi.	Stress at Initial Fracture (in bond), psi.
Tension, parallel to grain of paper[a]	2 240 000	18 000	19 600	
Tension, perpendicular to grain of paper[a]	1 080 000	9 700	11 800	
Compression, parallel to grain of paper[a]	2 290 000	8 700	17 700	
Compression, perpendicular to grain of paper[a]	1 290 000	6 900	14 400	
Bending perpendicular to laminations, axis of specimen parallel to grain of paper			22 000	
Torsion, axis of specimen parallel to grain of paper[a]	289 000		2 820	2200

[a] Data taken from Reference (1).

1. Fatigue tests conducted at different speeds with rotating-cantilever-beam type fatigue machines have shown that the fatigue strength at 10^7 cycles decreased from 6300 psi. at a speed of 500 rpm. to 5300 psi. at a testing speed of 14,000 rpm. However, an increase in specimen temperature with increasing testing speed was found to occur as a result of hysteresis damping. When the fatigue strengths of specimens run at different speeds were all adjusted to a common temperature of 77 F. there was found to be less difference between tests run at different speeds. When adjusted to a common temperature the fatigue strengths at 10^8 were found to vary from 6000 psi. at 500 rpm. to 5600 psi. at 14,000 rpm., and the fatigue strengths at 10^6 cycles varied from 7000 psi. at 500 rpm. to 6200 psi. at 14,000 rpm. (see Fig. 5).

2. The effect of variations in temperature was to cause the fatigue strength at 10^7 cycles to decrease from 11,900 psi. at −75 F. to 2800 psi. at 320 F. (see Fig. 8).

3. The effect of a deep notch was to decrease the fatigue strength at 10^7 cycles from 5800 psi. to 3100 psi. for tests operating at 5200 rpm., air temperature of 77 F., and relative humidity of 50 per cent. The stresses reported were nominal stresses based on the diameter of the specimen at the root of the notch. The relationship between the fatigue strength of notched and unnotched specimens was found to depend greatly upon the number of cycles at which the comparison was made. (See Fig. 9.)

4. A definition of fatigue failure has been proposed, together with a means of determining the time of fatigue failure from records of the load-deflection relationships. The effect of fatigue cracks and relaxation due to creep on the load-deflection characteristic of this material under bending loads has been determined, and the effect of a change in the arbitrary value of the change in stiffness used to determine fatigue failure has been studied. (See Fig. 15.)

5. Fatigue tests in bending on a constant amplitude-of-deflection type fatigue machine indicate the fatigue strength at 10^7 cycles to be 6700 psi. for a completely reversed stress cycle at a testing speed of 1720 rpm., a tem-

perature of 77 F., and a relative humidity of 50 per cent. The corresponding fatigue strength obtained from rotating-cantilever-beam fatigue tests, at the same testing speed, the same temperature, and the same number of cycles, was 6200 psi., or about 7.5 per cent lower. This difference may be due, in part, to the effect of temperature on the stiffness of the specimen. It may also be due, in part, to the fact that the rotating-cantilever-beam fatigue test actually subjects the specimens alternately to bending flatwise of the laminations and to bending edgewise of the laminations. However, it does not seem likely that this difference was significant, since inspection of the specimens tested revealed that fatigue cracks occurred in substantially the same manner on the flatwise side of the specimens for tests in both types of machines.

The difference in results may also be due to the fact that in one machine the amplitude of deflection of the specimen was constant throughout the life of a test whereas in the other machine the load applied to the rotating cantilever-beam specimen was constant during the test. This difference became significant when the development of fatigue cracks or an increase in temperature caused a decrease in the stiffness of the specimen. This decrease in stiffness caused a decrease in the amplitude of the applied load for tests in the constant-amplitude-of-deflection type machine, and an increase in deflection of the specimen for tests in the rotating-beam type machine. The result of this difference in behavior was to cause the conditions of the test to tend to become more severe in a rotating-beam type machine than in a constant-amplitude-of-deflection machine when fatigue cracks began to develop in the specimen.

It does not follow from the above, however, that the significant stress (in the region in which fatigue cracks appeared) had a constant amplitude throughout the life of a specimen tested in the rotating-cantilever fatigue machine, or that the significant strain had a constant amplitude throughout the life of a specimen tested in a constant-amplitude-of-deflection type machine. Instead the amplitude of the significant *stress* probably increased in a rotating-cantilever fatigue test, when a crack developed in a specimen, because the cracks caused a change in the geometry of the specimen with a consequent change in the distribution of stresses. Also the amplitude of the significant *strain* probably increased in a constant-amplitude-of-deflection fatigue test when a crack developed in the specimen because the cracks caused a decrease in the stiffness of the cracked part of the specimen. This change in stiffness resulted in a redistribution of strain throughout the specimen so that the amplitude of the strain in the region of the crack was increased and the amplitude of the strain in other parts of the specimen was reduced.

6. The effect of range of stress on the fatigue strength in bending fatigue tests was to cause the fatigue strength at 10^7 cycles to decrease from 6700 psi. at a mean stress of zero (completely reversed stress cycle) to a fatigue strength of 4500 psi. for a mean stress of 16,000 psi. in tension. The stresses given are the initial values of stress for tests at 1720 cycles per minute, temperature of 77 F., and relative humidity of 50 per cent. (See Fig. 17.)

7. The effect of range of stress on the torsional fatigue strength at 10^7 cycles was found to cause a decrease in fatigue strength from 790 psi. at zero mean stress to a fatigue strength of 650 psi. at a mean stress of 2500 psi. (See Fig. 19.) The stresses given for torsion fatigue tests are the initial values of the shearing stresses developed during the tests, and were computed from the ele-

mentary equation for torsion of circular cross-section members. Because of the anisotropic nature of this material, the stress values shown do not accurately represent the magnitude of the stresses developed.

8. A comparison of the torsion fatigue strength (measured in terms of shearing stresses) with the bending fatigue strength (measured in terms of tensile stresses) showed that the fatigue strength in torsion was approximately one eighth the fatigue strength in bending. This wide difference in the fatigue strength was due to the low fatigue strength of the bond between the laminations. The fatigue cracks developing in specimens tested in torsion were observed to form parallel to the laminations.

9. A comparison between the results obtained in this series of tests with available test results upon similar material (10) shows fair agreement between bending fatigue tests in completely reversed stress cycles. The only other data on fatigue tests of this material that have come to the attention of the author, are contained in a paper by Field (10). He used two methods of defining fatigue failure, one of which was the appearance of a fatigue crack and the second was essentially a change-in-stiffness method in which a different technique was used from that used in the tests reported in this paper. The fatigue strength at 10^7 cycles obtained by Field with his change in stiffness method of defining fatigue failure was about 15 per cent higher than the corresponding fatigue strength obtained by the author for the laminate described in this paper.

In the tests reported in this paper, visible fatigue cracks were present at the number of cycles for which fatigue failure was said to have occurred under the change-in-stiffness method of defining fatigue failure; however, Field (10) has reported that fatigue cracks were not visible in his specimens until sometime after the number of cycles at which the complete failure was indicated by the change in stiffness method which he used. This discrepancy may serve to illustrate the difficulty of detecting fatigue failure by visual inspection for the appearance of fatigue cracks.

Acknowledgments:

The project described above was part of the work of the Engineering Experiment Station of the University of Illinois, Dean M. L. Enger, Director, in the Department of Theoretical and Applied Mechanics of which F. B. Seely is Head. The author wishes to express his gratitude to F. B. Seely for making this project possible, and for assisting in preparing the manuscript. The author is greatly indebted to W. J. Worley, W. J. Gailus, and W. M. Owen who conducted most of the tests reported in this paper. A portion of the tests reported were carried out as senior theses by W. J. Galius and W. M. Owen. Acknowledgment is also due R. L. Sutherland, J. W. McNabb, and Browning Jacobs for assistance in the preparation of this paper.

It is a pleasure to acknowledge the generous cooperation of G. J. Muller of Taylor Fiber Co., who supplied the material and the information regarding its manufacture.

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DISCUSSION

MR. T. MCLEAN JASPER[1] (*by letter*).—This paper is exceedingly interesting in that it brings out several very interesting phenomena.

During the emergency just past the use of paper and wood laminates has been greatly advanced. Such structures as airplane envelopes and a great many other important stressed members have already demonstrated a reliability which is having a very great effect on the expansion of the use of laminates. It is felt that one of the most important test phenomenon, brought out by the author's tests, is contained in Figs. 7 and 8. The use of laminates is almost exclusively appropriate to atmospheric temperatures and below. The rapid reduction in quality of endurance at higher temperatures precludes many applications above about 100 F.

The airplane type seems very well suited for the application. Since the specific gravity of most of these laminates is around 1.4, the quality of strength per unit of weight is very attractive and if the cost per unit of strength per unit of weight is considered, I would predict that the paper and wood laminates have a very important economic field to occupy.

The data on speed of testing indicate relatively little difference in the endurance limit. The values indicated by Fig. 4 are what might be expected when it is understood that as the speed is increased the tendency for vibration to increase slightly the stress above what is actually measured is always there. This is, of course, a phenomenon which appears in service as well as in testing, but the difference between service conditions and carefully controlled laboratory testing conditions may vary much more widely.

MR. J. A. BENNETT[2] (*by letter*).—Mr. Findley has presented an unusually complete group of results which is of interest to any one working on fatigue problems.

It would be of interest to know, in Figs. 13 and 14, at what point fatigue cracks were first detected. Also I should like to know the approximate size of cracks at the time of failure in bending. It appears that there may have been a drop in the stress range before the formation of the first crack, and it would be worth-while to know more definitely about this. Glocker, in Germany, has reported that in metals damaged by fatigue the outer layers of a specimen do not carry as much stress as would be expected from the applied load. The effect is small, being detected only by X-rays, but it should result in decreased stiffness of the specimen. The decrease is probably too small to be measured in metals, but is it not possible that a similar phenomenon is responsible for the decreased stress range observed in the fatigue of plastics?

The difference in properties between metals and plastics is emphasized by a comparison of the results reported in this paper with work done at the National Bureau of Standards and reported in National Advisory Committee for Aeronautics Technical Note 992. In R. R. Moore tests of notched specimens of S.A.E. X4130 steel, failure was defined as having taken place when the deflection of the specimen reached a predetermined value. However, the value chosen was 0.0002 in. as compared with the 0.1 in. which Mr. Findley used in his experiments. Of course, the tests are not exactly comparable, but the difference in magnitude is startling.

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[2] National Bureau of Standards, Washington, D. C.

MR. REGINALD B. BLAND[3] (*by letter*).—The author is to be complimented on his able handling of a very difficult problem.

The writer at one time directed some fairly extensive tests, for a large airplane manufacturer, on certain types of plastic laminates. This material had unusually high internal damping so that the specimen temperature was considerably above ambient temperature even for the relatively slow testing speed of 1800 rpm. Since sub-resonance-type fatigue testing machines were used, changes in specimen modulus with temperature would change the resonant frequency of the fatigue testing machine, thus making load control somewhat critical during the early stages of a test. This trouble with load control was later cured by changes in the testing machine, but an unexpected virtue of the testing method was brought out: that the slight reduction of the effective modulus of elasticity of the material resulting from an incipient fatigue crack caused a considerable *increase* of load which would rapidly complete the failure. Hence, in all cases where failure resulted after temperature stabilization had taken place, the number of cycles between the initiation of the crack and the failure was a negligible proportion of the total number of cycles, which considerably simplified the definition of failure.

In regard to the tests on rotating-cantilever specimens, the significance of the nominal stress values computed using the usual beam formula of Mc/I may be open to question. The reason for this is that the material has widely different proportional limits in tension and in compression, the proportional limit apparently being much less for compressive stresses. As a result, whenever the bending moment is such that the compressive stress as computed by beam formula exceeds the proportional limit, a certain amount of plastic flow takes place at the outside, most highly stressed fiber. The simple beam formula is then no longer valid and the effect of increasing the load beyond the above value is to *reduce* the compressive stresses and to *increase* the tensile stresses from the computed values. Effectively this means that the mean stress is no longer zero and the stress is no longer completely reversed. Also, the varying stresses will not agree with the computed values.

While this effect may not greatly affect the results of the subject paper, the writer would like to mention it at this time, as it is the writer's opinion that the rotating-beam type of test can frequently lead to misinterpretation in this regard.

In regard to the tests on notched specimens, the various reasons advanced by the author for not calling the ratio of the fatigue strength of the unnotched specimens to the fatigue strength of the notched specimens the "stress concentration factor," do not appear valid if the term is preceded by the words "effective" or "experimental." Despite the fact that the ratio includes the over-all effect of many different factors, it still indicates the over-all reduction caused by the notch and hence can legitimately be used in design problems, etc.

The writer does not agree with the author in his explanation for the behavior of the notched specimens. The fact that the stresses below the base of the notch are triaxial is not considered significant, as it seems improbable that the fatigue failure would initiate in a zone sufficiently far below the surface to permit the radial stresses to attain a large enough value to affect the fatigue strength materially. Rather, it seems that the state of stress at the base of the notch is biaxial tension and, further, is not constant around the circumference of the notch due to the marked anisotropy of the material. Unfortunately, the notch selected for this work is not one that can be handled by mathematical analysis and hence the magnitude of the circumferential stress cannot be determined, although the concentration factor can be estimated as probably lying between 3.5 and 4.0.

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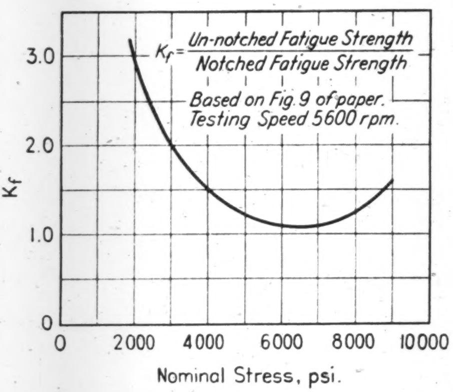

FIG. 1.—Variation of Effective Stress Concentration Factor in Fatigue with Nominal Stress at Base of 45-deg. Notch.

Concentration factors of this magnitude introduce another complicating factor in that the strain rate at the base of the notch is much higher than for a simple specimen without stress raisers. The introduction of a stress concentration factor of 3.5, for the tests that were conducted at 5200 rpm., is roughly equivalent to running tests on an unnotched specimen, at the same nominal stress level, at over 18,000 rpm. Such high strain rates are restricted to a very small volume at the base of the notch, and in combination with the wide hysteresis loops resulting from plastic flow may cause severe local heating of the material due to its low heat conductivity.

To better point out that factors beyond those mentioned by the author are present, the accompanying Fig. 1 has been prepared, which is based on the *S-N* curves presented in Fig. 9 of the author's paper. It will be noted that the effective stress concentration factor in fatigue follows the usual law of variation for low stresses, although the reduction to a minimum value takes place rather more rapidly than is generally found. Following the attainment of a minimum value at a nominal stress of approximately 6500 psi., however, the effective concentration factor abruptly increases. This suggests strongly that factors beyond that of normal stress alleviation play a prominent part. Localized heating, as suggested, may be one factor. Others that may play important parts are: strain rate, changes in strain distribution due to the anisotropy of the material in combination with heating effects, inequality of tensile and compressive proportional limits, etc. The data presented are inadequate to permit the evaluation of these factors.

The lack of agreement between fatigue strength and modulus of rupture does not surprise the writer. The writer is beginning to feel that the static failure and the fatigue failure are not necessarily related, as they may represent two different phenomena. The writer hopes to be able to express his views further on this subject in the near future.

MR. E. C. O. ERICKSON[4] (*by letter*).—Mr. Findley has recognized the difficulty of defining failure in fatigue tests of such materials as plastics. In constant amplitude-of-deflection tests of wood and plywood[5] in flat plate machines we have used an arbitrary procedure for determining the end point of the test. Small micro switches set at the mid span of the cantilever specimen operated to stop the machine when the throw at this point increased by a small amount from its initial value. The increase in throw to be used was determined from a series of auxiliary tests in which condition of the specimens after stoppage of the machine by various settings of the micro switch was examined. In tests of Papreg[6] the "deflection method" devised by Field[7] was used. While our experience in this subject is limited, it would seem that Field's method is a more logical and less arbitrary basis than the use of the micro switch or the method described by Mr. Findley. It seems obvious that definition of failure or of the end point in fatigue tests of some materials needs further exploration.

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Mr. Findley's paper is of particular value and interest to us in that it includes the only available data of which we know on the effect of subnormal and abnormal temperatures on the fatigue-strength of paper-base phenolic laminates.

MR. ALBERT G. H. DIETZ[8] (*by letter*).—Mr. Findley's paper not only contains much data of value respecting the fatigue strength of laminated paper plastic, but points out directly or by inference a number of factors of importance in the testing of materials of this nature.

First is the necessity for defining fatigue failure. In this series of tests several different criteria had to be established, more or less arbitrarily, depending upon the type of test. For the rotating-beam test a certain pre-determined deflection defined failure. For the constant-deflection tests, cracks reducing the stiffness of the specimen by a pre-determined amount defined failure, with some complications in the tests conducted at a mean stress not equal to zero. In the absence of any generally accepted definition, Mr. Findley's criteria of failure are as logical as any. On the other hand, if other investigators adopt different definitions of failure, it becomes difficult if not impossible to correlate the results of different tests. Some agreement as to what constitutes fatigue failure is necessary. Possibly several sets of criteria are needed, depending upon the use to which a given material is to be put.

Second is the importance of rate of strain upon the behavior of the material. Different results are obtained, at least partly because of temperature rises in the material. This in turn points out the hysteresis effects to be expected with materials of this kind. More striking, however, is the disparity between the results obtained with the bending fatigue tests, and the static modulus of rupture tests, in which the rate of strain was comparatively low. The same appears to be true of shearing stress. The importance of the time factor in these tests becomes apparent and must be considered in correlating the results of different tests.

Mr. Findley makes an excellent analysis of the loss of stiffness caused by cracking in specimens subjected to alternating stresses with a mean not equal to zero. It may be that the difference between the theoretical curves of Fig. 12 and the actual ones is caused by slight crushing of the material in the vicinity of the crack, which would prevent the crack from closing up instantaneously on the compression cycle.

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[8] Assistant Professor of Structural Design and Materials; Dept. of Building Engineering and Construction, Massachusetts Institute of Technology, Cambridge, Mass.

A number of other points of interest are brought out. Specimens machined seven months ahead of testing yielded poorer results than specimens machined two weeks before. Degradation of the surface or some other aging characteristic seems to be involved and indicates that similar aging of material in use may have to be considered in design. The steady decrease in fatigue strength with rising temperature, with an indicated drop of approximately 75 per cent in rising from −75 F. to +320 F. is another factor of importance in design.

MR. WILLIAM N. FINDLEY (*author's closure by letter*).—The author wishes to express his appreciation to the discussors for their valuable contributions to this subject. The discussors have raised a number of questions some of which are of a controversial nature and cannot be satisfactorily answered without experimental evidence which does not exist at the present time. With this limitation in mind, the author will respond to all issues on which he has comments which may help to clarify this difficult problem.

Mr. Jasper's comment that the rapid reduction in quality of endurance at higher temperatures precludes many applications above about 100 F. may be somewhat misleading, inasmuch as Fig. 8 shows that the fatigue strength of this material is most affected by changes in temperature at low temperatures. In fact, the curve shown in Fig. 8 appears as though the fatigue strength might be nearly independent of temperature at temperatures above 300 F. were it not for the fact that the material begins to char and otherwise deteriorate at the elevated temperatures.

The actual behavior of the rotating-cantilever-beam fatigue machine used in this investigation did not substantiate Mr. Jasper's observation that the effect of speed of testing may have been caused by an increased tendency for vibration at the higher testing speeds. Since most of the tests were conducted at speeds above the resonant speed for the machine and specimens used, the small vibrations which occurred tended to decrease as the speed of testing increased.

In reply to Mr. Bennett's question concerning the test data shown in Fig. 13, a fatigue crack in the specimen was observed at 20,000 cycles. This crack was on the side of the specimen which was subjected to the greatest tensile stress. With the criterion of fatigue failure as defined in the present paper, however, failure occurred at about 30,000 cycles. At this number of cycles the fatigue crack probably was about $\frac{1}{16}$ in. deep in the specimen which was about $\frac{1}{2}$ in. thick. However, the depth is not accurately known. At 56,000 cycles it was observed that a crack had formed on the opposite side of the specimen.

It may be worth noting that the breakdown of this particular specimen (see Fig. 13) began as a crack on the side of the specimen having a high tensile stress, progressed inward about $\frac{1}{32}$ in., then spread as a separation between the laminations at about $\frac{1}{32}$-in. depth. After a number of cycles, the crack progressed inward again about $\frac{1}{32}$ in. and spread again as a separation along the laminations. This process was repeated until the crack was about $\frac{5}{32}$ in. deep at which point a crack was observed to have started on the opposite side of the specimen. No data are available on the number of cycles at which a fatigue crack was visible for the test reported in Fig. 14.

The author is doubtful whether the difference noted by Mr. Bennett between the deflection used in this paper to define failure of plastic specimens and that used in an N. A. C. A. Report to define failure of steel specimens actually represents a difference in properties between metals and plastics, inasmuch as the value chosen in both cases was arbitrary. A small increase in deflection might have been used in the case of plastics as well as steel. The author used a relatively large increase in deflection, for the purpose of defining fatigue failure, in order that the results might be more accurately reproduced. The results were more easily reproduced with a large increase in deflection because the increase in deflection was very gradual as failure began to take place, and the determination of the number of cycles corresponding to a given small increase in deflection was somewhat uncertain. On the other hand, the deflection increased rapidly as failure approached complete fracture and the determination of the number of cycles corresponding to a given deflection was more positive.

It is well to note that the amount of deflection corresponding to a given size of crack would be influenced by the size and shape of the specimens used.

The difference between the rate of growth of the crack in a subresonance type of fatigue testing machine compared to that of the constant-amplitude-of-deflection type machine as pointed out by Mr. Bland has also been observed by the author in recent tests with a subresonance type of fatigue testing machine. It may be well to mention at this point that the rotating-cantilever-beam type of fatigue testing machine has very similar characteristics to that of the subresonance type of machine with respect to the rapidity of crack growth.

Mr. Bland has pointed out one of the limitations of the flexure formula with relation to the rotating-beam fatigue test. However, it should be pointed out that a more precise analysis of the stresses is impossible or at least impractical with present methods of stress analysis. It seems to the author that a more practical approach to the problem might be to abandon the technique of stress computation in favor of direct strain measurement. It should also be noted that the objections raised by Mr. Bland to the use of the simple beam formula apply equally well to all types of fatigue testing machines which subject the specimen to flexure, rather than only to the rotating-beam type of machine as implied by Mr. Bland.

The discussion of the failure of the notched specimens by Mr. Bland is very interesting and seems to emphasize further the difficulty of evaluating the stress-concentration factor. The author disagrees with Mr. Bland in his use of the term effective stress-concentration factor. In the opinion of the author the effective stress-concentration factor should be used to define the ratio between the maximum stress observed in actual tests of a stress raiser to the nominal stress at the stress raiser computed from the ordinary formulas of mechanics of materials, and the ratio thus determined should not include other factors such as differences in rate of strain, temperature, surface finish, residual stresses or changes in structure of the material by cold working, etc.

It seems to the author that all three of the methods of detecting fatigue failure described by Mr. Erickson are equally arbitrary in that none of them detects the inception of the fatigue crack. Therefore, it would seem that the only claim for superiority of one method over another would be on the basis of reliability and simplicity.

The explanation given by Mr. Dietz for the difference between the theoretical curves of Fig. 12 and the actual ones is probably the correct explanation.

THE EFFECT OF WIDTH AND OF SPAN-DEPTH RATIO ON THE FLEXURAL STRENGTH OF LAMINATED PLASTICS*

By E. M. Schoenborn,[1] George R. Proctor,[2] and Jaime Carvajal[2]

Synopsis

The inadequacy of current testing procedures for the determination of the flexural characteristics of rigid plastic materials has promoted a comprehensive study of the test method. A program to evaluate the effect of different test variables on the modulus of rupture and modulus of elasticity has been undertaken in an effort to develop better testing techniques and to gain a more intimate knowledge of their significance.

This report describes briefly the results obtained to date from over five hundred flexural tests carried out in these laboratories. Laminated phenolic sheet, grades X and C, and vulcanized bone fibre sheet were tested at span-depth ratios of 8, 12, 16, and 24 to 1 and in widths varying from $\frac{1}{4}$ in. to 1 in. Specimens were cut both lengthwise and crosswise from $\frac{1}{4}$ and $\frac{1}{2}$-in. sheet stock.

Nearly all tests were remarkably consistent, calculated values of flexural strength and modulus exhibiting average deviations within ± 3 per cent of the mean of 5 to 10 determinations. In general, calculated maximum fiber stress at rupture was found to decrease, and the modulus to increase, with increasing span-depth ratio. The effect of width of specimen appeared anomalous, particularly for the phenolic materials, since samples cut lengthwise showed increasing strength, while those cut crosswise gave decreasing values, as the sample width increased. Both the flexural strength and modulus calculated for the fiber were independent of width over the range covered. Only two thicknesses of sheet were included in this investigation so that no general statements regarding the effect of specimen depth can be made at this time.

Several correlations of the observed data were made which show that the formulas currently being used to calculate ultimate flexural stress and modulus of elasticity are not rigorous for the materials studied. A plot of breaking load P *versus* specimen dimensions, L/bd^2, however, indicates P to be a power function of the latter group of variables, the exact function being dependent upon the nature and direction of the material. A more fundamental approach to the behavior of inelastic materials in flexure is, therefore, indicated.

Means for determining the physical properties of plastics by standardized methods and procedures have become of increasing importance, particularly where applications of a structural character are concerned. Furthermore, a knowledge of the behavior of

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these materials, as interpreted through sound testing methods, is a prime consideration in engineering design. Among the more important mechanical properties which must be evaluated before any significant comparison of rigid materials can be made is that of flexural strength.

Because of the uncertainties existing in an interpretation of the flexural test method as a consequence of the large number of variables involved and because of the anomalous results obtained by methods currently in use, a broad program directed toward a careful evaluation of the test method has been undertaken.

A series of round-robin tests was carried out some time ago by Section F, Subcommittee I of A.S.T.M. Committee D-20 on Plastics and the results were summarized by W. A. Zinzow.[3] The need for modification of the then existing flexural test method was apparent and specific changes were recommended. At the same time, a continuation of the study covering an even wider range of test variables and materials appeared desirable so that the present investigation was initiated.

A preliminary report describing the general philosophy of approach was presented to A.S.T.M. Committees D-9 on Electrical Insulating Materials and D-20 on Plastics at their meetings held in Atlantic City, October 24 to 27, 1944. Since that time over 500 tests have been made on two types of phenolic-laminated material and on vulcanized fibre, and it is the purpose of this report to present briefly the results obtained and the implications of these results with regard to future work.

EXPERIMENTAL

Testing Equipment:

All flexural tests were carried out in a specially constructed air-conditioned room maintained at 77 F. and 50 per cent relative humidity. Samples of phenolic previously cut to size were conditioned in this environment for a period of at least six weeks prior to testing. The fibre was conditioned in a circulating air oven at 50 C., stored in desiccators and tested immediately upon removal therefrom in the manner prescribed in A.S.T.M. Tentative Methods of Conditioning and Classifying for Conditioning Plastics and Electrical Insulating Materials for Testing (D 618–44 T).[4]

A Baldwin Southwark Tate-Emery Universal Testing Machine of 60,000-lb. capacity was employed for all tests. This unit is equipped with an automatic stress-strain recorder which, by means of a special adaptation of a set of extensometers for measuring relative crosshead motion, permits the recording of a load-deflection diagram for each test. The recorder eliminates the necessity for tedious dial gage readings and permits a single operator to perform the necessary operations easily and quickly. An attachment especially developed to utilize an extensometer for measuring relative crosshead motion is described later. A standard set of Sonntag flexure tools having supports and loading nose with $\frac{1}{8}$-in. radii, standard dial indicators, and other necessary fixtures are available.

A general view of the testing machine is shown in Fig. 1; the present arrangement for the flexural tests is shown in Figs. 2 and 3.

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[3] See p. 376.

[4] 1944 Book of A.S.T.M. Standards, Part III, p. 1385.

Extensometer Attachment.—In order to obtain an accurate load-deflection diagram with the recorder, a high magnification extensometer is being used to measure relative crosshead motion. For hard materials, indentation at the supports and nose is found to be negligible so that the motion of the platen relative to the fixed crosshead serves to give a good indication of beam deflection. For softer materials, a modification of this scheme will have to be devised and it is hoped a means can be found for measuring sample deflections directly from the specimen and of recording them with the stress-strain instrument.

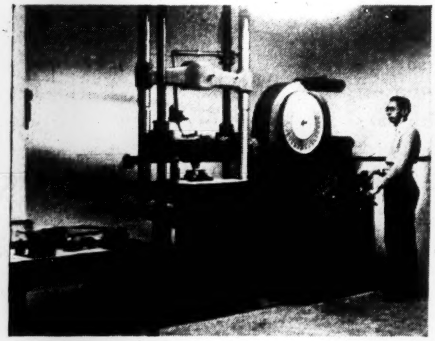

FIG. 1.—General View of Baldwin Southwark 60,000-lb. Testing Machine in Air-Conditioned Laboratory.

The extensometer attachment (Fig. 4) consists essentially of two short brass rods, one sliding within the other, to which the knife-edges of the extensometer can be securely fixed. The lower rod is screwed into a heavy base which rests on the fixed crosshead. The upper brass rod is engaged through a ball and socket joint with a long thin steel rod which slides through a hollow brass fixture containing a set-screw. This fixture is machined to fit into the steel wedge used to suspend the upper set of a pair of Templin tension grips. In this way the device is kept in alignment and adjustment of the fixed crosshead is readily made without removing the extensometer. A high magnification extensometer with a range of 0.20 in. is currently being used at a magnification ratio of 100. Thus, a deflection of 0.01 in. is recorded on the strip chart through a distance of 1 in.

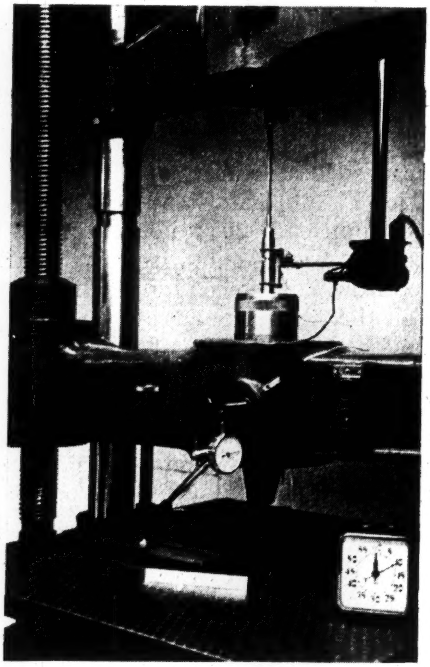

FIG. 2.—Flexural Test Set-up Showing Extensometer Arranged to Record Relative Crosshead Motion.

Materials:

While it is planned to continue investigation of the flexural strengths of numerous other plastics, the tests described herein were confined to grades X and C phenolic-laminated sheet material and to Bone Grade vulcanized fibre. A large quantity of these samples cut both crosswise and lengthwise of the sheet was generously supplied by Continental-Diamond Fibre Co. and National Vulcanized Fibre Co., Newark, Del. Other samples not yet tested include phenolic-laminate and Pregwood supplied by Synthane Corp. and Formica Insulation Co., respectively.

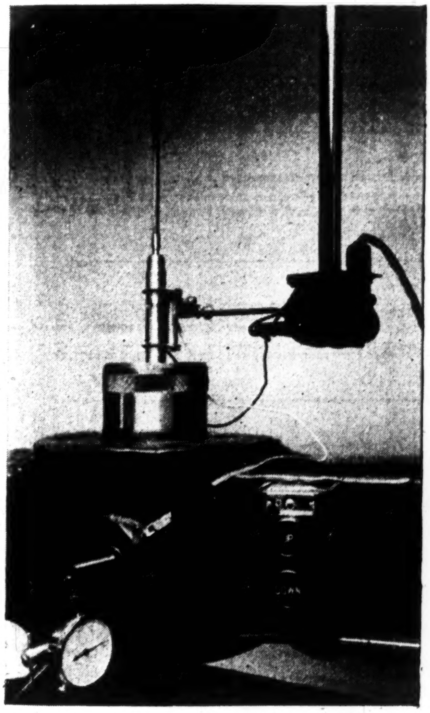

FIG. 3.—Extensometer Attachment in Position.

Test Variables:

Data were obtained on the above materials at span-depth ratios of 8, 12, 16, and 24 to 1 using samples of $\frac{1}{4}$ and $\frac{1}{2}$-in. depths and $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and 1-in. widths. The testing speed utilized was determined for each sample size from the formula as recommended in A.S.T.M. Tentative Method of Flexural Test of Plastics (D 790 - 44 T)[5]:

$$N = 0.01L^2/6d \quad \text{.........(1)}$$

where:

d = depth of beam as tested in inches,

L = distance between points of supports (span) in inches, and

N = rate of crosshead motion in inches per minute.

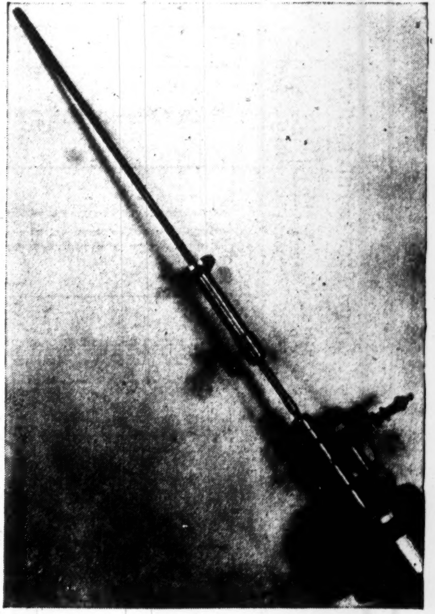

FIG. 4.—Extensometer Attachment for Flexural Test.

The rate of crosshead motion was maintained as close as possible to this calculated value by manual control using a dial indicator and stop watch. Previous tests indicated a considerable variation in ultimate flexural strength and modulus of elasticity with speed of testing but this variable was not studied in the present series.

At least five and, in numerous cases, as many as ten samples

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[5] 1944 Book of A.S.T.M. Standards, Part III, p. 1634.

TABLE I.—OBSERVED DATA AND CALCULATED RESULTS.

Number of Samples	Depth, d, in.	Width, b, in.	Span, L, in.	Breaking Load, P, lb.	Flexural Strength, S, psi.	Average Deviation, per cent	Span-Depth Ratio, L/d	Modulus of Elasticity E_B, psi.	Average Deviation, per cent	
				GRADE X PHENOLIC LAMINATE						
5..	0.254	0.253	2	138	25 500	±3.8	8	1 380 000	±2.6	Lengthwise
5..	0.257	0.250	3	93	25 400	±3.2	12	1 390 000	±2.7	
8..	0.257	0.256	4	70	25 000	±1.6	16	1 470 000	±2.3	
5..	0.256	0.246	6	44	24 500	±1.7	24	1 570 000	±1.5	
8..	0.255	0.501	2	289	26 700	±1.9	8	1 280 000	±3.3	
5..	0.258	0.503	3	201	27 200	±2.2	12	940 000	±1.6	
8..	0.254	0.502	4	143	26 400	±1.5	16	1 440 000	±5.8	
5..	0.254	0.508	6	93	25 500	±2.1	24	1 670 000	±1.9	
5..	0.256	0.762	2	535	31 600	±4.0	8	1 710 000	±0.7	
5..	0.257	0.761	3	335	29 400	±1.1	12	1 730 000	±1.8	
5..	0.255	0.764	4	237	28 600	±0.6	16	1 860 000	±4.6	
5..	0.257	0.764	6	166	29 700	±2.1	24	2 010 000	±3.6	
8..	0.258	0.996	2	740	33 600	±1.8	8	1 760 000	±0.8	
5..	0.257	1.000	3	470	32 000	±1.2	12	1 770 000	±2.5	
5..	0.254	1.000	4	333	31 200	±2.5	16	1 850 000	±3.2	
5..	0.257	1.003	6	225	30 700	±0.8	24	1 940 000	±1.2	
5..	0.257	0.253	2	181	33 100	±2.4	8	1 730 000	±2.1	Crosswise
5..	0.257	0.249	3	116	31 800	±1.9	12	1 860 000	±3.8	
5..	0.257	0.250	4	85	30 800	±1.3	16	1 880 000	±1.6	
5..	0.258	0.256	6	56	30 500	±1.0	24	2 100 000	±1.0	
8..	0.256	0.493	2	352	32 300	±1.3	8	1 530 000	±2.7	
5..	0.256	0.504	3	231	31 500	±2.0	12	1 170 000	±3.9	
8..	0.256	0.500	4	173	31 700	±1.5	16	1 860 000	±3.7	
5..	0.256	0.503	6	111	30 400	±1.7	24	2 100 000	±2.2	
5..	0.256	0.766	2	480	29 000	±2.2	8	1 310 000	±2.1	
5..	0.255	0.762	3	299	27 600	±2.9	12	1 360 000	±1.2	
5..	0.255	0.763	4	220	25 800	±3.6	16	1 460 000	±6.3	
6..	0.257	0.761	6	136	24 100	±2.3	24	1 470 000	±1.7	
9..	0.256	1.001	2	715	27 700	±2.4	8	1 190 000	±6.8	
7..	0.257	0.999	3	389	26 800	±1.6	12	1 330 000	±2.2	
5..	0.257	1.001	4	292	26 400	±2.6	16	1 560 000	±5.5	
5..	0.258	1.001	6	186	25 000	±3.0	24	1 420 000	±3.0	
5..	0.511	0.504	4	697	31 300	±2.8	8	1 750 000	±2.7	Lengthwise
5..	0.509	0.503	6	453	31 300	±1.0	12	1 910 000	±1.0	
4..	0.511	0.500	8	339	30 800	±3.0	16	2 040 000	±1.2	
5..	0.512	0.500	12	219	30 100	±0.6	24	2 090 000	±1.3	
5..	0.512	0.505	8	280	25 400	±1.9	16	1 500 000	±1.5	Crosswise

GRADE C PHENOLIC LAMINATE

5..	0.257	0.251	2	110	19 900	±1.6	8	890 000	±1.9	Lengthwise
5..	0.258	0.250	3	69	18 800	±1.4	12	930 000	±3.0	
5..	0.262	0.252	4	52	18 500	±1.5	16	980 000	±1.5	
8..	0.259	0.254	6	33	17 500	±2.2	24	980 000	±3.9	
5..	0.258	0.503	2	225	20 200	±2.0	8	820 000	±3.7	
5..	0.260	0.501	3	148	19 700	±2.5	12	970 000	±4.0	
8..	0.259	0.502	4	104	18 500	±2.1	16	970 000	±5.4	
6..	0.259	0.501	6	65	17 400	±2.4	24	1 070 000	±3.5	
5..	0.274	0.754	2	455	24 000	±2.5	8	920 000	±2.3	
5..	0.274	0.757	3	288	22 900	±3.0	12	1 030 000	±3.6	
5..	0.274	0.757	4	204	21 200	±1.5	16	1 070 000	±2.4	
5..	0.275	0.759	6	131	20 700	±2.0	24	1 100 000	±1.7	
5..	0.272	0.996	2	587	23 900	±2.3	8	920 000	±3.3	
5..	0.269	1.002	3	379	22 500	±5.1	12	970 000	±2.1	
5..	0.272	0.999	4	263	21 300	±2.3	16	1 050 000	±1.6	
5..	0.273	1.001	6	168	20 200	±2.7	24	1 120 000	±6.6	
5..	0.263	0.251	2	138	23 900	±2.0	8	1 040 000	±3.0	Crosswise
5..	0.260	0.253	3	80	21 000	±2.2	12	960 000	±0.7	
5..	0.261	0.245	4	60	21 500	±2.5	16	1 070 000	±1.9	
8..	0.262	0.251	6	40	21 200	±2.2	24	1 190 000	±2.4	
5..	0.261	0.502	2	271	23 900	±1.6	8	940 000	±2.5	
5..	0.261	0.501	3	165	21 800	±3.2	12	1 000 000	±3.1	
8..	0.262	0.499	4	125	22 100	±2.3	16	1 090 000	±2.3	
8..	0.262	0.502	6	78	20 400	±3.9	24	1 150 000	±1.7	
5..	0.275	0.758	2	389	20 500	±1.9	8	890 000	±0.8	
5..	0.273	0.762	3	247	19 600	±1.6	12	960 000	±3.0	
5..	0.275	0.761	4	180	18 900	±2.0	16	970 000	±1.7	
5..	0.275	0.766	6	117	18 200	±1.5	24	1 050 000	±1.7	
5..	0.262	1.000	2	548	24 000	±0.9	8	940 000	±3.2	
5..	0.261	1.000	3	332	23 400	±4.2	12	970 000	±1.3	
5..	0.258	0.998	4	225	20 400	±1.9	16	990 000	±3.3	
5..	0.274	0.999	6	150	18 000	±0.9	24	1 000 000	±1.2	
5..	0.533	0.501	4	535	23 400	±1.8	8	1 090 000	±1.8	Lengthwise
5..	0.515	0.503	6	310	21 000	±2.6	12	1 120 000	±3.2	
5..	0.530	0.500	8	256	21 900	±0.5	16	1 250 000	±1.1	
5..	0.529	0.503	12	160	20 400	±0.7	24	1 300 000	±1.9	
5..	0.522	0.503	8	203	17 900	±2.7	16	1 070 000	±0.8	Crosswise

Continued on next page.

TABLE I.—OBSERVED DATA AND CALCULATED RESULTS.—*Continued.*

Number of Samples	Depth, *d*, in.	Width, *b*, in.	Span, *L*, in.	Breaking Load, *P*, lb.	Flexural Strength, *S*, psi.	Average Deviation, per cent	Span-Depth Ratio, *L*/*d*	Modulus of Elasticity E_B, psi.	Average Deviation, per cent	
				VULCANIZED BONE FIBRE						
5..	0.256	0.495	2	259	24 000	±1.9	8	900 000	±0.8	Lengthwise
5..	0.257	0.518	3	165	21 600	±1.1	12	1 140 000	±7.4	
5..	0.255	0.502	4	119	21 900	±2.5	16	1 200 000	±2.4	
5..	0.257	0.490	6	77	21 200	±1.8	24	1 220 000	±3.5	
5..	0.254	0.754	2	363	22 100	±2.6	8	930 000	±2.5	
5..	0.256	0.755	3	242	21 900	±2.1	12	1 230 000	±2.6	
5..	0.256	0.758	4	180	21 800	±1.4	16	1 210 000	±2.9	
5..	0.254	0.766	6	117	21 100	±0.7	24	1 240 000	±1.7	
5..	0.257	0.991	2	481	22 400	±1.2	8	920 000	±7.7	
5..	0.258	0.993	3	316	21 600	±2.1	12	1 290 000	±6.0	
5..	0.255	0.991	4	232	21 700	±1.6	16	1 140 000	±0.7	
5..	0.257	0.989	6	148	20 300	±2.6	24	1 220 000	±1.8	
5..	0.253	0.496	2	178	16 900	±1.4	8	650 000	±5.7	Crosswise
5..	0.259	0.496	3	118	15 900	±2.0	12	810 000	±3.6	
5..	0.256	0.498	4	85	15 400	±0.5	16	850 000	±2.5	
5..	0.255	0.496	6	54	15 100	±1.0	24	820 000	±1.0	
5..	0.256	0.756	3	176	16 100	±1.5	12	950 000	±6.8	
5..	0.258	0.739	4	128	15 300	±1.2	16	750 000	±3.3	
5..	0.259	0.753	6	84	14 900	±0.7	24	800 000	±3.4	
5..	0.259	0.993	2	362	16 300	±1.9	8	600 000	±4.4	
5..	0.257	0.994	3	234	15 900	±2.4	12	800 000	±6.3	
5..	0.256	0.994	4	171	15 800	±1.3	16	750 000	±3.3	
5..	0.260	0.988	6	109	14 700	±1.5	24	800 000	±3.6	

(where greater variation of breaking load was noted) were successively tested under identical conditions of operation. All samples were carefully aligned flatwise on Sonntag supports with contact edges rounded to a radius of $\frac{1}{8}$ in., any burr resulting from the cutting operation having previously been carefully removed from the sample with sandpaper. The thickness and width of each specimen were measured to the nearest 0.001 in., the span to the nearest $^1/_{64}$ in.

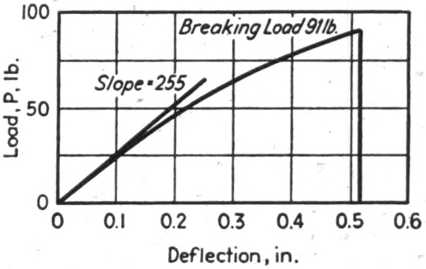

FIG. 5.—Typical Load-Deflection Diagram Grade X Phenolic-Laminate, Tested Lengthwise.
Nominal size: 8 by $\frac{1}{2}$ by $\frac{1}{2}$ in. Span-depth ratio: 24 to 1.

Each sample was tested as a simple beam loaded at the center, the loading nose being identical in shape and dimensions with the end supports. Since the materials tested were relatively hard and since inspection showed that indentation was negligible at the loads encountered, effect of indentation on total deflection was not an appreciable factor.

RESULTS

The observed data and calculated results are summarized in Table I. In view of the voluminous amount of data obtained and in the interests of economy of space, only average values are presented here. The greatest ranges of variables were covered with $\frac{1}{4}$-in. thick sheet. Sufficient $\frac{1}{2}$-in. phenolic stock was not conveniently available in as great a variety of widths, but the few data given are useful for purposes of comparison. Data on $\frac{1}{16}$, $\frac{1}{8}$, and 1-in. depths will be presented subsequently.

The ultimate flexural strength (modulus of rupture), S, was computed for each specimen from the measured dimensions and breaking load according to the formula:

$$S = 3PL/2bd^2 \ldots\ldots\ldots (2)$$

where:

b = width of beam as tested in inches,
P = load in pounds, and
S = maximum fiber stress in pounds per square inch.

This formula applies only to materials for which the maximum fiber stress remains linearly proportional to strain up to the point of rupture and consequently cannot be rigorously applied to the type of materials studied. Lacking an exact relationship, however, it has been applied as a convenient means of reporting the flexural characteristics of a material under various conditions of test.

The modulus of elasticity was computed from the formula:

$$E_B = \frac{L^3}{4bd^3}\left(\frac{P}{Y}\right) \ldots\ldots\ldots (3)$$

where:

E_B = modulus of elasticity in bending in pounds per square inch, and
(P/Y) = slope of initial straight line portion of load-deflection curve in pounds per inch deflection.

The slope of the tangent to the load-deflection curve is obtained from the initial portion of this curve as automatically traced by the stress-strain recorder for each specimen. A typical load-deflection diagram is shown in Fig. 5.

Although the values of ultimate strength and of modulus of elasticity are reported as the mean of at least five determinations, the average deviation expressed as per cent are also given. In the case of both properties, the average deviation from the mean of all samples tested are generally well below ± 3 per cent. This is striking evidence of the precision with which data were taken and lends added confidence to the results obtained.

the fact that equal linear increments on such a scale represent equal percentage changes in the variable plotted. This obviates the sometimes misleading pictorialization frequently resulting from use of arithmetic scales. The average deviations are shown in several cases by small vertical lines drawn above and below the data points. They are not shown for all of the data plotted since the same or smaller order of deviation applies approximately to all the tests described.

It is of interest that, in the case of every material tested, there is, in general, a decrease in ultimate flexural strength, S, with increasing span-depth ratio. The rate of decrease, furthermore, is not the same for all samples, but appears to depend both on the nature of the material and on the direction in which the sheet is tested. The few data on ½-in. thick phenolic also vary in this manner as shown in Fig. 6.

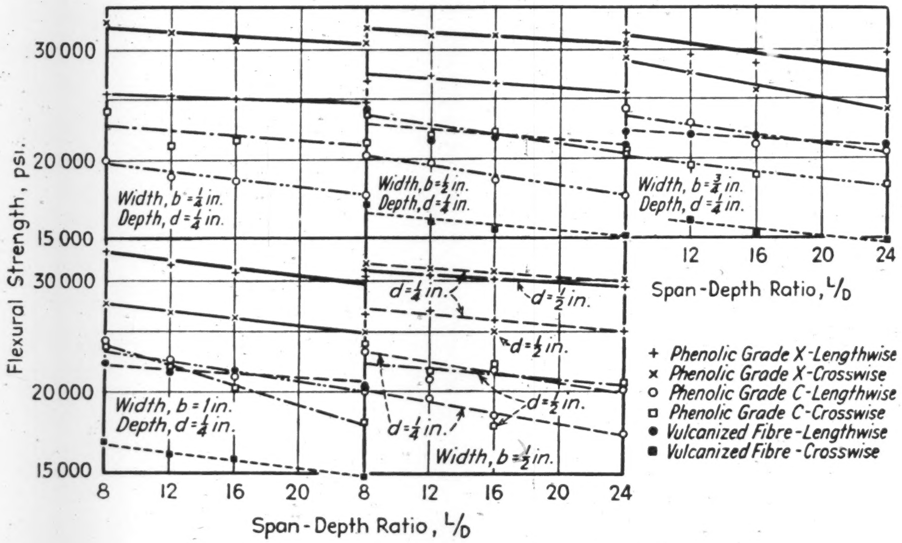

FIG. 6.—Flexural Strength *versus* Span-Depth Ratio.

DISCUSSION

Effect of Span-Depth Ratio:

The effect of span-depth ratio on the flexural strength is shown in Fig. 6 where average values of S are plotted *versus* L/d on semi-logarithmic scales. The advantage of using a logarithmic ordinate in this case lies, as is well known, in

Effect of Width:

In the instance of the phenolic-laminate, the data show an anomalous trend with respect to increasing width. Specimens cut lengthwise of the sheet exhibit an increasing flexural strength with increasing width while values for those cut crosswise decrease with increasing width. Vulcanized fibre appears to be more consistent in this respect, particularly at the higher span-depth ratios. The variation of strength with width of specimen could have been shown more directly by using width as a parameter in Fig. 6. This procedure was not feasible, however, without use of an expanded scale for flexural stress, since the data would have fallen very close together.

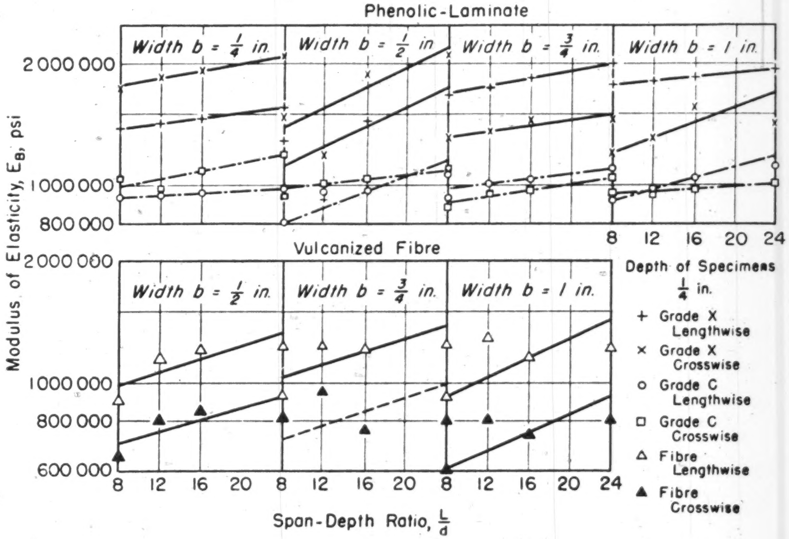

Fig. 7.—Modulus of Elasticity *versus* Span-Depth Ratio.
Depth of specimen : ¼ in.

Modulus of Elasticity:

The values obtained for the modulus of elasticity as a function of span-depth ratio are shown in Fig. 7. Here the modulus is found to increase with increasing span-depth ratio, despite the fact that the data for fibre appear to be less consistent and to scatter more widely than the phenolic. For a given span-depth ratio, however, the modulus increases with increasing width in the case of phenolic specimens cut lengthwise and decreases with increasing width in the case of those cut crosswise of the sheet. The modulus appears less dependent on width in the case of fiber.

The anomalous variation in values computed for the modulus of elasticity with increasing span-depth ratio cannot be satisfactorily explained at this time. Factors such as indentation at the loading edges, take-up in the threads of the machine and low sensitivity of the autographic chart may contribute to this effect. Since the rate of

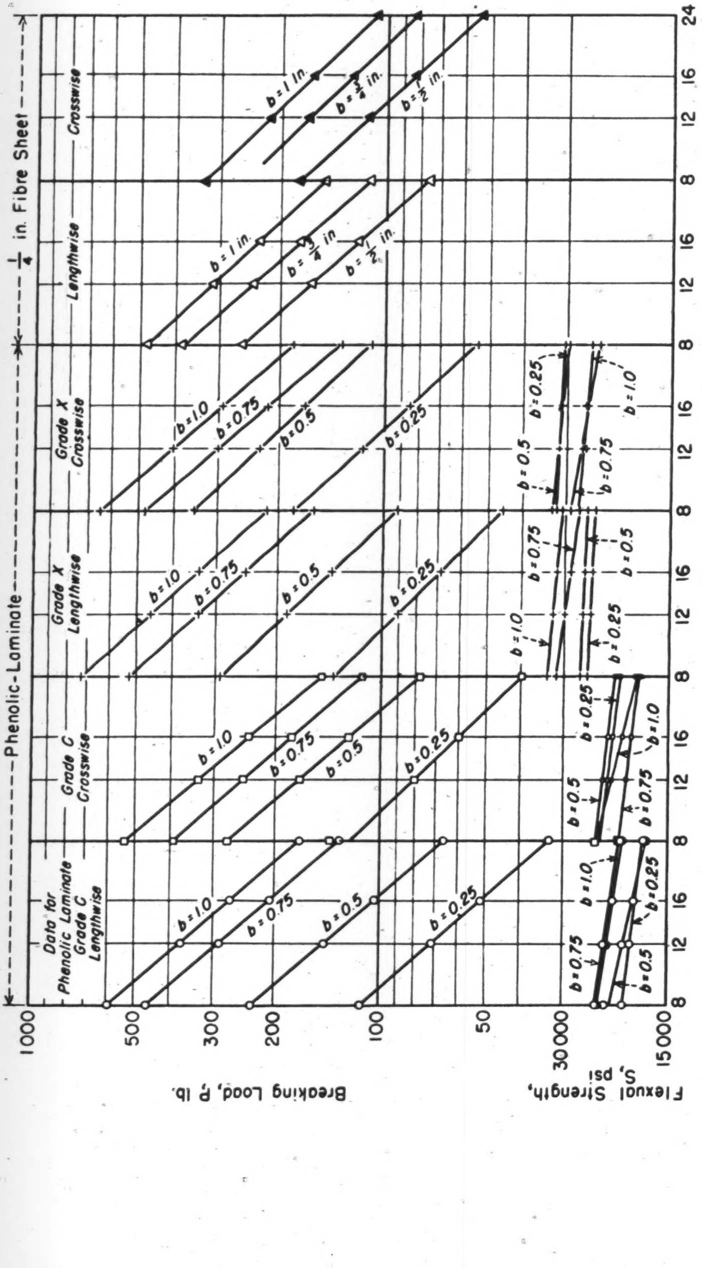

FIG. 8.—Breaking Load and Flexural Strength *versus* Span-Depth Ratio.

crosshead motion increases with span-depth ratio, according to Eq. 1, it is possible that the use of increased testing speeds may account at least in part for this variation. A study of these different factors is currently being undertaken.

Correlation of Observed Data:

The values of modulus of rupture and of modulus of elasticity, were, as previously pointed out, computed from formulas derived for elastic materials. Since these formulas are known not to hold for plastics, it is of interest to correlate the observed data solely on the basis of the variables measured. A number of different methods of plotting were tried, two of which are shown in Figs. 8 and 9. Here the breaking load, P, is plotted on logarithmic paper *versus* span-depth ratio, L/d, using width as a parameter. The remarkable consistency of observed data is clearly shown. Width as a parameter is eliminated by plotting P *versus* L/bd^2 as shown in Figs. 9 and 10. The abscissae may here be thought of as the product of span-depth ratio and cross-sectional area normal to length. Since this group occurs in the formula for modulus of rupture, this method of plotting can be looked upon as a test of the application of the formula for these materials. The curves of Figs. 9 and 10 show the formula not to apply in all cases since the breaking load here is found to be

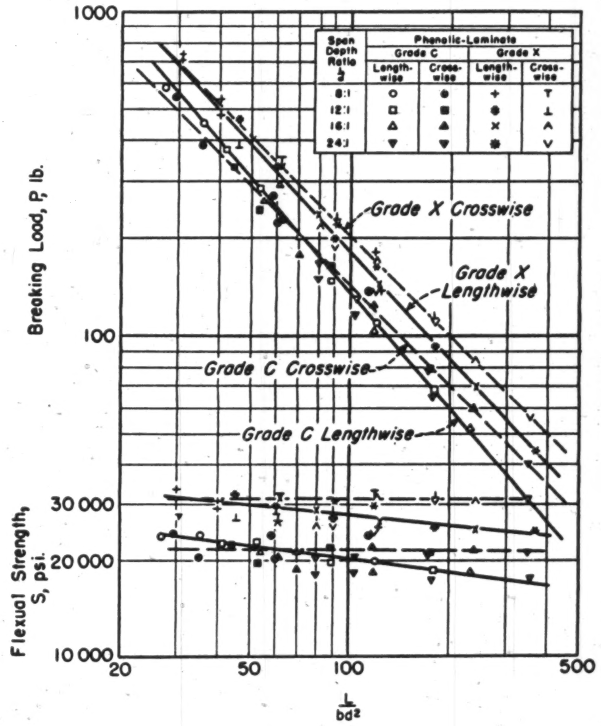

Fig. 9.—Breaking Load and Flexural Strength *versus* L/bd^2.

a power function of L/bd^2, that is, of sample dimensions. Calculated ultimate flexural strength is shown plotted in the lower portion of one of these figures against the same group for purposes of comparison.

In the case of the laminated phenolic tested crosswise, it is of interest to note that the slope of the P *versus* L/bd^2 curves is very close to -1, that is, S is essentially constant. The latter fact is also evident from the S *versus* L/bd^2 curves which, for the crosswise tests, have slopes essentially equal to zero. Samples tested lengthwise exhibit greater deviation, the slopes for grades X and C being about -1.09 and -1.17, respectively. Slopes for the fiber tested lengthwise and crosswise are -1.08 and -1.04, respectively. An empirical expression relating breaking load to specimen dimensions can be obtained from these data having the form

$$P = C(L/bd^2)^{-n} \qquad (4)$$

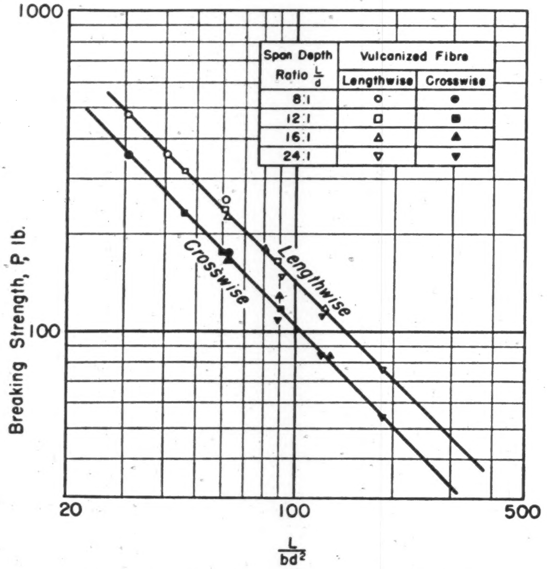

FIG. 10.—Breaking Load *versus* L/bd^2.

where values of the constant C and exponent n depend only upon the composition and direction of the specimen.

It must be remembered that Eqs. 2 and 3 are derived on the following assumptions: "that the beam is symmetrical, initially straight, homogeneous, of material having equal stiffness in tension and compression, that it is not stressed above its elastic limit by the load, that the bending is slight and that the plane of the external forces coincides with a plane of symmetry."[6] It is evident, therefore, that these formulas cannot be expected to apply to plastic materials, particularly at the point of rupture. The demonstrated deviation of the exponent n from the theoretical value of unity by as much as 17 per cent is proof that the flexure formula must be used with great care.

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[6] J. B. Johnson, "Materials of Construction," Eighth Ed., John Wiley & Sons, Inc., New York, N. Y. (1939).

The data presented here, although restricted to but three types of materials, indicate in a general way the effect of the test variables on the flexural characteristics of these plastics and serve to predict the trends which can be expected from the test method utilized. This study emphasizes a need for similar investigations on other materials and a yet more fundamental approach to plastic behavior under carefully controlled test conditions.

Acknowledgment:

The authors gratefully acknowledge the encouragement and helpful suggestions of A. P. Colburn, G. E. Landt, E. O. Hausmann, G. H. Mains, S. W. Place, and F. L. Stiegler during the course of this investigation.

DISCUSSION

MR. PHILIP S. TURNER (*by letter*).[1]—The authors are to be commended for their direct approach to this important subject. The detailed description of the testing procedure and presentation of the data furnish the reader a basis for critical analysis of the conclusions reached. The limitation of the conclusions to the specific materials studied is particularly desirable.

It is unfortunate that the deflections were measured by the relative crosshead motion, since this method combines the errors due to deformations at both the nose and supports and would cause the apparent modulus to be lower in tests at the lower span-depth ratios. It is not believed that inspection of the specimens is an adequate criterion of this effect. All of the materials investigated are nonisotropic in the three-dimensional sense and have much lower moduli of elasticity in the direction perpendicular to the sheet. A fairly large elastic deformation in this direction may affect the results without leaving any appreciable permanent deformation.

The variation of flexural strength with span-depth ratio is in general agreement with results obtained at the National Bureau of Standards on similar materials and with results obtained by other investigators on typically brittle materials such as cast iron and concrete. A number of factors contribute to the shape of the curves of flexural strength *versus* span-depth ratio which should not be a straight line on either rectangular or semi-logarithmic plots. The analysis of the data appears to be developed around the assumption that straight lines should be obtained.

One of the factors contributing to the lower flexural strength at larger span-depth ratios is the increased probability of finding a flaw in the highly stressed portion of the specimen. In his paper "Statistical Theory of the Effect of Dimensions and Method of Loading upon the Modulus of Rupture of Beams,"

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[1] Organic Plastics Section, National Bureau of Standards, Washington, D. C.

John Tucker, Jr.[2] demonstrates that the variation in flexural strength of concrete with span-depth ratio is dependent on the nonhomogeneity of the material. Since reinforced plastics are nonhomogeneous by definition the theory should apply also to these materials.

Another effect which is particularly applicable in tests of plastics at span-depth ratios greater than 16:1 is the large deflections and probable slippage at the supports.

High-modulus low-strength materials such as concrete and cast iron do not exhibit large deflections and consequently are not affected in this manner. Reductions in flexural strength of 20 per cent between span-depth ratios of 16:1 and 24:1 have been observed at the National Bureau of Standards for $\frac{1}{8}$-in. Grade C phenolic sheet. A large part of this reduction is attributable to the large deflections which cause considerable error in the bending moment calculated in the usual way.

Other types of laminates show a reduction at span-depth ratios below 10 because of shear failures. Examples of such materials are glass-fabric laminates and plywood having a low resin content.

The variation in flexural strength with span-depth ratio is therefore characteristic of the material being tested and not necessarily a characteristic of the test method. Tests at one selected span-depth ratio may give the wrong impression of the relative strength of two materials under different methods of loading.

The effect of width is also discussed by Tucker.[2] His analysis of the strength of concrete beams shows that flexural strength is independent of width. Tests on a variety of plastics at the National Bureau of Standards have shown that the flexural strengths of plastics are likewise independent of the width of the specimen. The author's results on the vulcanized fiber support this conclusion.

The reason for the anomalous behavior in the case of the grade C phenolic material is evident from the data presented. Apparently several sheets of material were used for preparing the specimens or, if these specimens were obtained from a single sheet, the specimens for a particular width were taken from a small area. The specimens having a width of $\frac{3}{4}$ in. have a range of thickness between 0.273 and 0.275 in.; those for the $\frac{1}{4}$ and $\frac{1}{2}$-in. widths have a range of thickness of 0.257 to 0.263 in. The specimens having a width of 1 in. appear to have been obtained from sheets of both thicknesses but with each group being taken from a single thickness. It does not appear likely that the sheets could have been adequately sampled and still have the specimens present the distinct independent ranges of thicknesses reported.

The precision of results obtained at the National Bureau of Standards on groups of 5 contiguous specimens of $\frac{1}{8}$-in. grade C phenolic laminate has been found to be sufficient to show a significant difference between different portions of a single sheet of commercial laminate under identical test procedure. The results for a sample representing all portions of a sheet will show much more variation, although the accuracy of the measurements is the same. The precision of the measurements is undoubtedly much better than the uniformity of the material. The precision of the data, therefore, does not serve as an indication of the validity of the results unless the material is properly sampled. The grade C material does not appear to have been properly sampled for the study of the effect of width.

The variation with span-depth ratio

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[2] John Tucker, Jr., "Statistical Theory of the Effect of Dimensions and of Method of Loading upon the Modulus of Rupture of Beams," *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 1072 (1941).

appears to be valid, at least it is not obviously invalid, except for the data obtained for the 1-in. wide specimens cut crosswise. The other results appear to have been based on comparable specimens.

The cause of the anomalous variation with width observed for the grade X material is not apparent but it might prove informative to review the technique of sampling employed.

An additional detail of the testing procedure which should be mentioned is the particular range of the testing machine which was used for the tests. The small loads encountered in flexure tests are not usually within the range of loads that can be measured accurately with a 60,000-lb. hydraulic testing machine without specific calibration. The authors should indicate the maximum of the range used in the tests.

MR. E. M. SCHOENBORN (*author's closure by letter*).—The authors are grateful to Mr. Turner for his very careful study of this paper and for emphasizing some of the important factors relating to the flexural properties of laminated plastics.

It may be pointed out that the determination of deflections by measuring relative cross-head motion was employed primarily for convenience since it permitted the use of high magnification extensometers in a simple manner. A newly developed deflectometer which measures deflections from the bottom of the sample has been used in subsequent tests. Use of this device eliminates the effect of indentation at the nose but does not account for it at the supports. Because stresses at the supports are lower and since the moduli are determined from the initial portion of the load-deflection curve when loads are small, it is believed this instrument will reduce further possibility of error from this source.

It is entirely possible that the anomalous behavior of certain of the materials tested is a result of improper sampling. Samples were received from the manufacturers cut to size so that knowledge either of the history of the sheets or of the locations from which samples were cut were not available. The authors concur, however, on the importance of adequate sampling of such nonhomogeneous materials.

Nearly all of the tests reported were carried out using a load range of 0 to 600 lb. although several of the larger samples at low span-depth ratios required use of the 0 to 6000-lb. range. There is real need for a testing machine (or appropriate modification) operating over a much smaller range than the former, particularly for thin specimens where precise determination of the modulus is required.

DIMENSIONAL STABILITY OF PLASTICS*

BY ROBERT BURNS[1]

SYNOPSIS

Because of inherent insulating properties, rigid plastics play an important part in the design and manufacture of precision electrical apparatus. Almost invariably, practical design considerations require that the plastics have reasonable structural possibilities since it is rarely practicable to disassociate completely electrical and structural functions.

This paper discusses one of the important factors in the successful use of plastics in precision devices, namely, dimensional stability. Since plastics are organic compounds, one must be prepared to accept a degree of instability not usually encountered in metals. The measurement of this property is therefore of prime importance to the user of plastics since the data provide a basis for design adjustment which frequently is the difference between failure and success.

The various types of dimensional change are reviewed. Data illustrating the separate effects of humidity, drying, and cycling procedures are submitted. The influence of fabricating processes such as compression or injection molding, and sheeting, is included.

TYPES OF DIMENSIONAL CHANGE

The discussions herein are confined to what might be termed zero-stress conditions, that is, where no external stresses such as compression, tension, etc., are applied. They therefore exclude deformation under load, heat distortion, and similar procedures where elastic or plastic flow results from externally applied stresses. In any engineering consideration of zero-stress dimensional change it should, of course, be remembered that such changes can occur simultaneously with those produced by externally applied stresses. Zero stress dimensional change may also oppose the changes caused by externally applied stresses. For example, oriented sheet may grow thicker rather than thinner under low external pressure. Cold flow values at moderate external pressures also will vary with the degree of molded stress in the sample.

Plastic parts, or test specimens, change in dimensions becaue they are inherently unstable, or are made so by manufacturing processes, or both. It is very important to keep in mind that all plastics, regardless of chemical composition, are potentially unstable dimensionally because it is virtually impossible to mold or form a part without introducing internal stress. In practice most commercial moldings, especially those produced by the injection process, are highly stressed.

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* Also published in ASTM BULLETIN, No. 134, May, 1945, p. 27.

[1] Bell Telephone Laboratories, Inc., New York, N. Y.

On the other hand, the situation is not reversible as even ideal molding conditions will not produce a stable part from an unstable material.

Inherently stable plastics can be defined as those which are not affected by atmospheric influences such as heat, moisture, or combinations thereof encountered in normal engineering use. Unstable plastics, of course, are those which are affected. As pointed out above, stable materials are frequently made unstable by internal molding stresses which later relieve themselves.

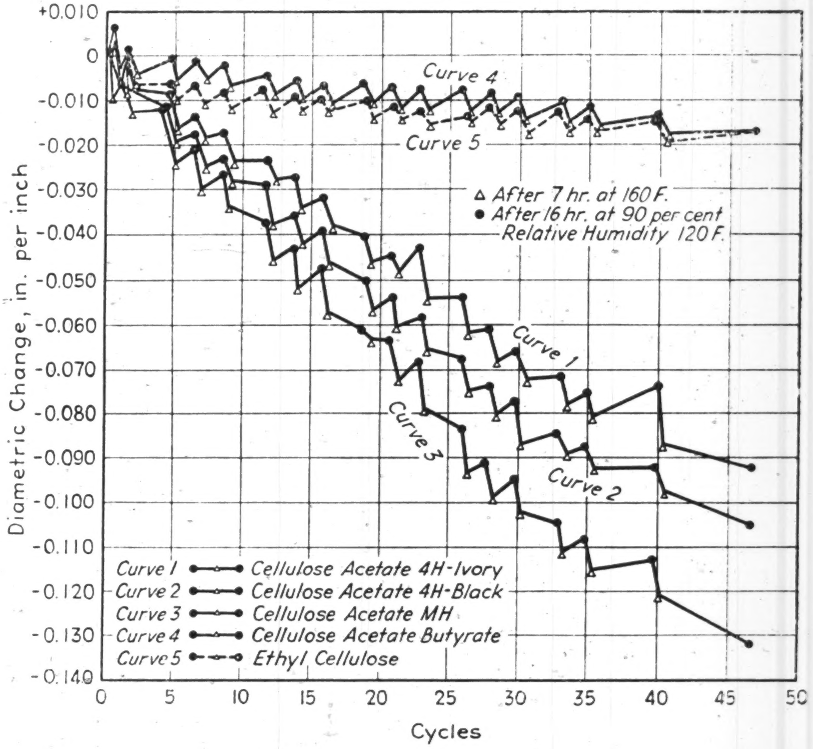

FIG. 1.—Diametric Change.

METHODS OF TEST

In establishing methods of test for dimensional stability, care must be taken that in our zeal for acceleration we do not introduce methods which are highly artificial, such as extremely high temperatures, or which apply to only a small part of the product. It is technically and economically unsound to require that all parts meet requirements necessary for the few.

Regarding choice of atmospheric conditions this is purely arbitrary and can be any reasonable state between ordinary room conditions and those which are obviously too severe. In the twenties we introduced the following: 2 days at 90 per cent relative humidity and 85 F. (representing a state of wetness attained during the summer), followed by 2 days at 120 F. (representing a state of dryness attained in a steam-heated room in the winter), or continuous exposure to either.

In 1940 we adopted a more accelerated test as follows: 16 hr. over a potassium nitrate solution, about 86 per cent relative humidity, at 120 F. followed by 7 hr. at 160 F. dry, or continuous exposure to either. Unless otherwise mentioned these conditions, or modifications thereof, are the basis for the data given herein. For example in testing thin sheets, it was desirable to use 120 F. for the drying part of the cycle to avoid the excessive warping which would occur in some materials at the higher temperature. Unless otherwise noted, the molded test specimen is a 3-in. diameter by $\frac{1}{8}$-in. thick disk, compression molded and presumably of low internal stresses. All "dry" measurements were made after cooling to room temperature in a desiccator jar over calcium chloride.

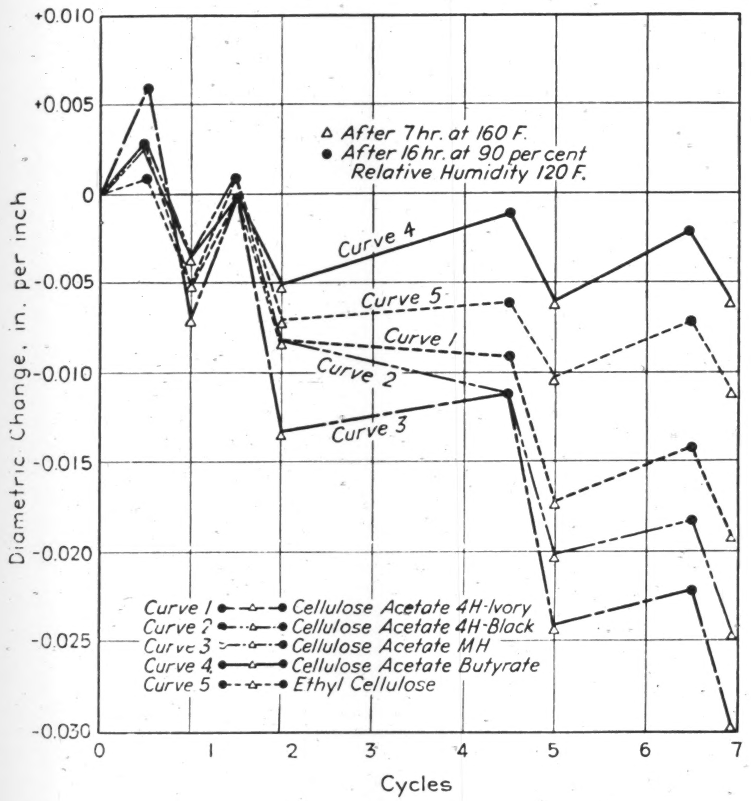

FIG. 2.—Diametric Change.

Expansion of First Seven Cycles of Fig. 1. (7 Cycles = 1 week.)

DATA AND DISCUSSION

In Fig. 1 are shown cycling data on compression molded specimens of several cellulosic compounds. The plasticizer content of the cellulose acetates was approximately 25 per cent, of the butyrate approximately 13 per cent. It will be noted that although the diametric increase due to humidification, and shrinkage due to drying, are somewhat similar for individual cycles in all compounds the downward slope (sometimes called age shrinkage) may vary substantially.

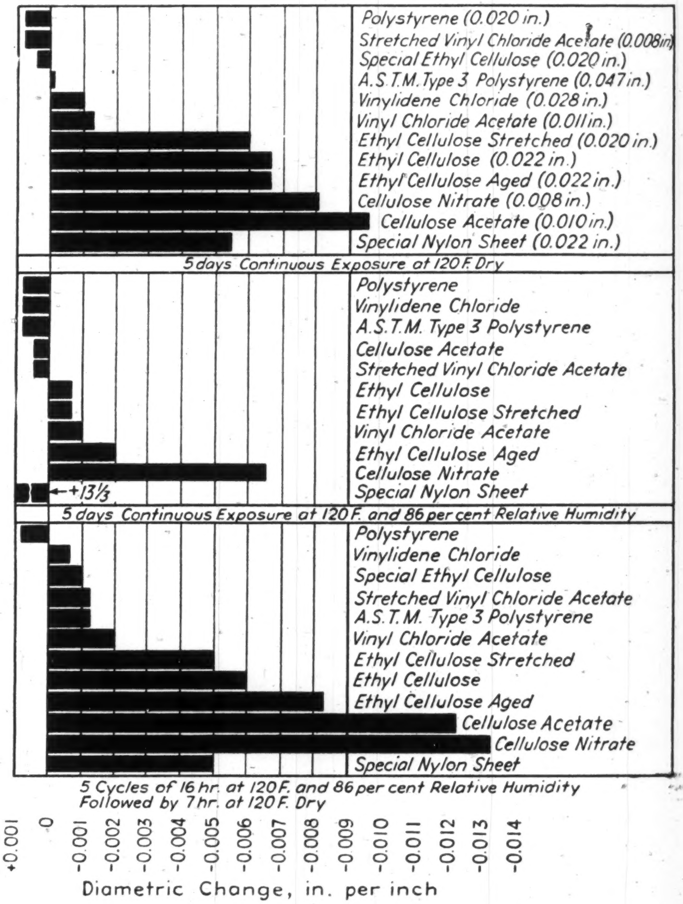

FIG. 3.—Diametric Change of Plastic Sheeting.

Figure 2 is an expanded view of the first few cycles, giving a more detailed picture of dimensional response of diameter to moisture and drying.

Figure 3 gives data on a variety of plastics in the form of thin sheeting. The specimens were 3-in. diameter disks cut from commercial sheets of undetermined composition. The cycle data are based on diametric measurements made at the end of the drying period.

Figure 4 shows diametric change of compression molded 3-in. diameter by $\frac{1}{8}$-in. thick disks.

Figure 5 illustrates the effects of plasticizer content and method of molding on diameteric change of cellulose acetate.

Tentative Methods of Test for Resistance of Plastics to Accelerated Service Conditions (D 756 – 44 T)[2]

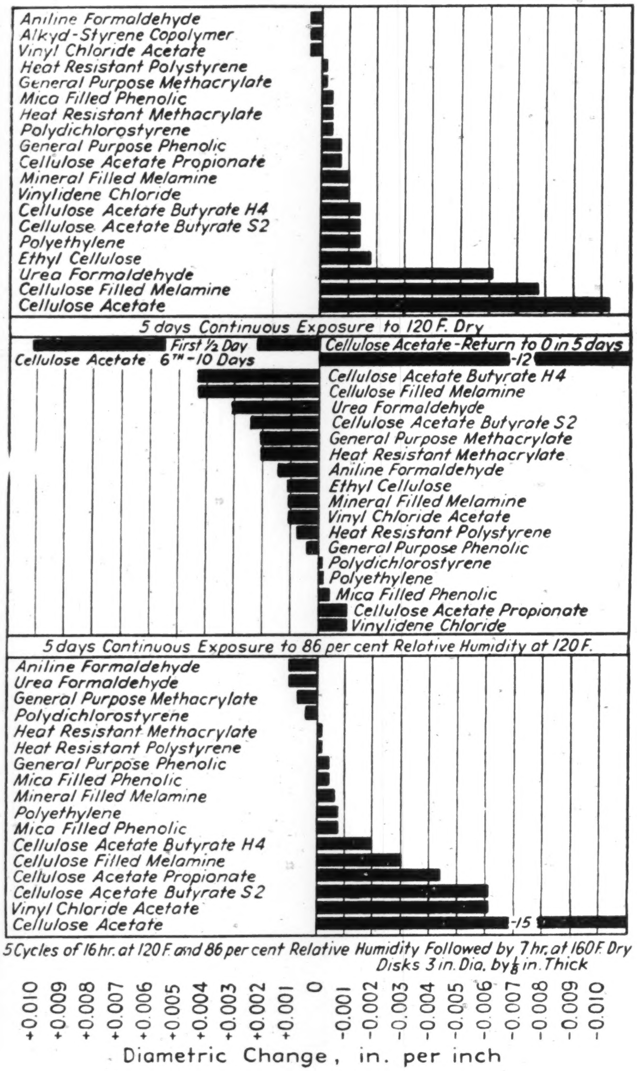

FIG. 4.—Diametric Change of Molded Plastics.

Figure 6 compares diametric change with weight change.

Figure 7 gives a comparison between the method used in this study and Procedure I of the A.S.T.M. and Federal Specification L-P-406.

The data provoke discussions

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[2] 1944 Book of A.S.T.M. Standards, Part III, p. 1663.

which may be of interest to the materials engineer. For example, the generally poor performance of some of the thin sheetings as compared to molding compounds of the same chemical type is striking. These laboratory results have been substantiated by actual experience. It is apparent that the methods of making thin sheeting produce internal stresses which restrict the use of such materials in precision applications.

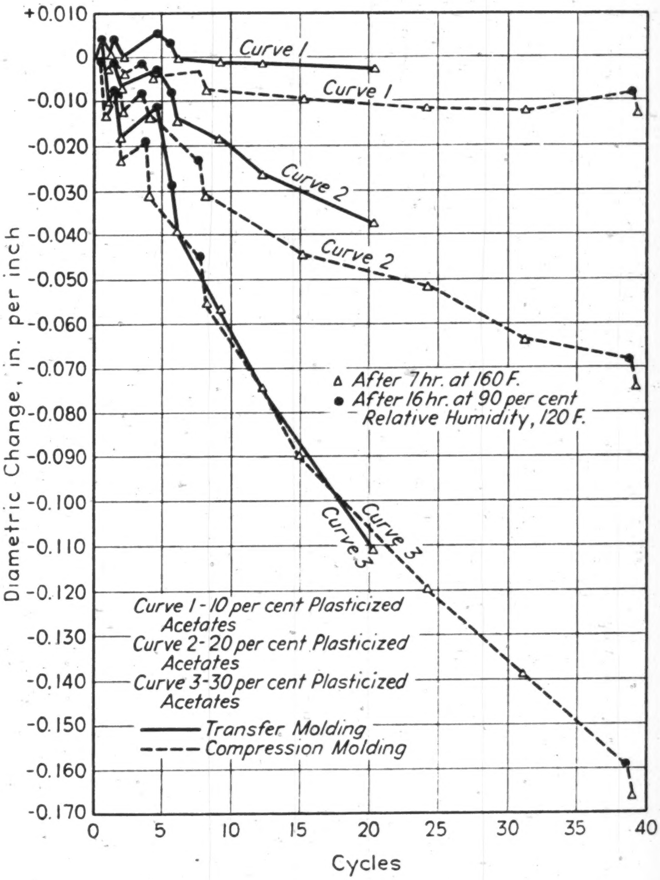

FIG. 5.—Diametric Change of 10, 20, and 30 per cent Plasticized Acetates.

In the plasticized cellulosic compounds it is common knowledge among technicians that the softer compounds are the less stable dimensionally. The quantitative expression (Fig. 5) of this generalization brings up the question of what actually happens during repeated cycles of humidifying and drying. That it is not due to plasticizer loss is apparent in Fig. 6 where high diametric shrinkage is accompanied by negligible loss of plasticizer.

Further explanation is found in the fact that in many of the compounds the decrease of diameter with repeated cycling is accompanied by an increase in thickness. A few typical data are as follows:

	Thicknesses Before and After 47 Cycles, in.	
	Before	After
Cellulose acetate, Hard	0.127	0.165
Cellulose acetate, Soft	0.124	0.178
Ethyl cellulose	0.125	0.138
Cellulose acetate butyrate	0.127	0.136

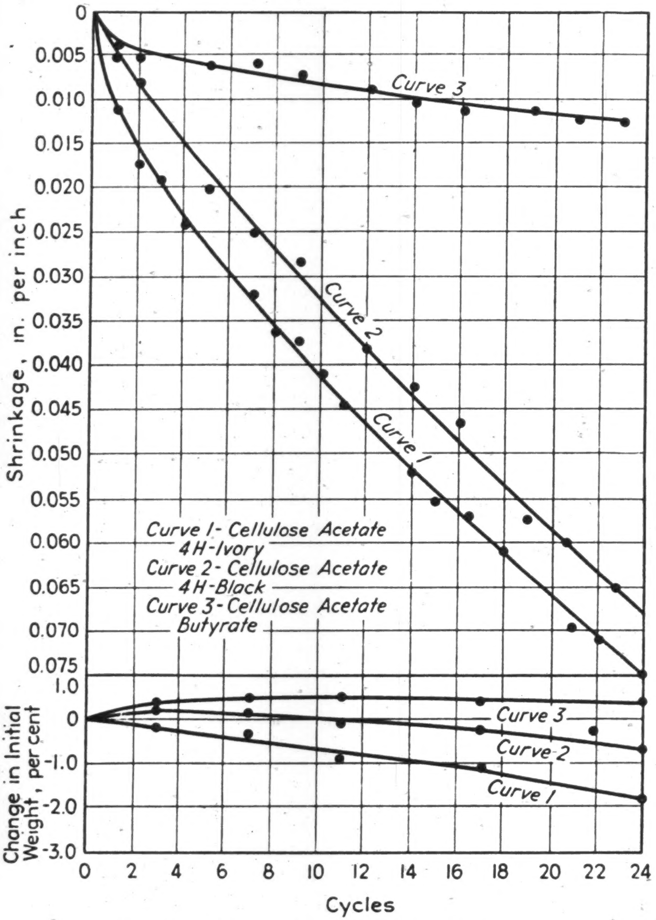

FIG. 6.—Diametric and Weight Changes.

These data suggest a "cold flowing" of the body of the disks as a result of forces exerted by contraction of the periphery. That this is a permanent plastic deformation is illustrated by the fact that thorough drying of the thickened specimens to remove any accumulated moisture results in practically no decrease in thickness. Inasmuch as most dimensional troubles in actual service are due to linear shrinkage, the increase in thickness is usually of little help. The phenomenon of self cold-flowing does not occur in the thermosetting compounds to an appreciable extent.

In choosing atmospheric conditioning procedures for dimensional stability studies, one must differentiate between those which evaluate materials for general use and those which are founded upon some unique service condition. The conditions used for this study are based on the first premise and are on the mild side with respect, for example, to outdoor conditions encountered by the military services. However, the technician must keep in mind that in common with most empirical testing we lose validity rapidly as we hasten results by extreme testing conditions. Speaking generally, it is desirable to qualify materials on data which are discreet and valid, and leave to the apparatus testing procedures the problem of determining performance at very unusual service conditions.

The more recently adopted Procedure I of A.S.T.M. Methods D 756 and Federal Specification L-P-406 is similar to the procedure used herein except somewhat more severe (24 hr. at 140 F. over sodium sulfate solution followed by 24 hr. at 140 F. dry). Procedure I, notwithstanding its severity, is generally acceptable except for very soft or temperature-sensitive materials where excessive warping tends to invalidate the test. A comparison of the two methods is shown on Fig. 7. It is interesting to note that both methods rate these cellulosic materials in the same order of preference from the standpoint of dimensional stability.

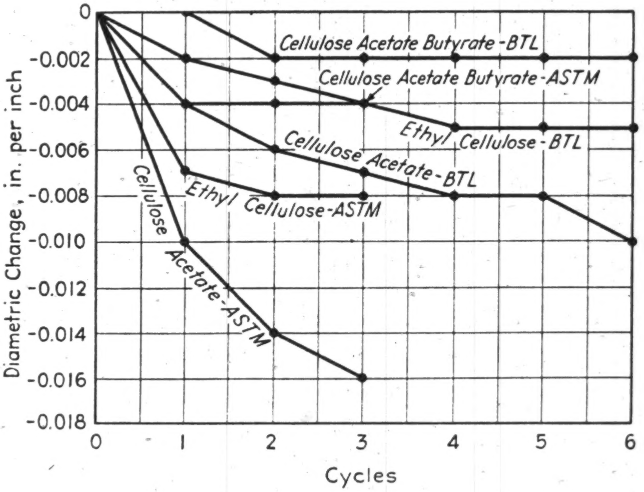

FIG. 7.—Diametric Change, Comparison of Methods.

In the practical application of plastics one must keep in mind that whereas the effect of humidity and mild elevated temperatures, whether used jointly or severally, is one involving at worst only a few mils per inch (15 would be an extreme case) the effect of the higher temperatures involving stress release is relatively violent. As an example, the vinyl chloride acetate sheeting (Fig. 3) appears to be superior to the ethyl cellulose. However, the sheet materials were dried in the cycling test at 120 F. instead of at 160 F. because the vinyl sheeting became egg-shaped at 160 F., and even at 140 F. The ethyl cellulose remained substantially circular up to temperatures of over 250 F.

It is not the intention of the foregoing to present final engineering data on the materials tested nor to pass on their relative merits for any particular application. It is, however, intended to emphasize that dimensional stability depends on manufacturing processes as well as on materials. The choice of cycling procedures, limiting values of permissible dimensional change, etc., are determined by the particular apparatus in mind, and where it is to be used. In addition, many plastics are available in a wide variety of types permitting the materials engineer substantial latitude.

Acknowledgment:

The author wishes to thank George H. Williams, Anne S. Wrubel, and others of the Laboratories' staff who rendered valuable assistance in this work.

THE EFFECT OF SPECIMEN SHAPE ON THE COMPRESSIVE STRENGTH PROPERTIES OF LATERALLY SUPPORTED PLYWOOD SPECIMENS*

By J. A. Liska[1]

Synopsis

Prism-shaped specimens have commonly been used for compression tests of wood and plywood, but hourglass-shaped specimens have been considered as possibly giving more reliable results because of improved end conditions and type of failure. This report presents the results of two series of tests performed at the Forest Products Laboratory to compare two forms of hourglass specimens (designated as types *A* and *B*) with prism-shaped specimens (designated as type *C*). In the principal series of tests, the specimens were all prepared in the normal manner with smooth ends, but the second series was designed to afford a comparison of the prism-shaped specimens (type *C*) with the hourglass specimens (type *B*) when the specimens were made with deliberately chipped and frayed ends, such as might be produced by poor fabrication.

The analysis of tests made on 200 specimens of two species and three plywood thicknesses and constructions, indicated that despite a difference in the mode of failure, the physical properties of the well-prepared prisms were in good agreement with those obtained on the two forms of hourglass specimens, and were slightly higher when small differences were noted. When the faces of the specimens were chipped and torn by improper preparation, the prism-shaped specimen (type *C*) showed a definite reduction in compressive strength as compared to well-prepared specimens of the same type and to those of the hourglass (type *B*) form. Little, if any, difference, however, in fiber stress at proportional limit or modulus of elasticity was observed between the poorly fabricated prisms and hourglass-shaped specimens (type *B*).

In the preparation of prism-type compression specimens, care should be used in fabrication to insure smooth end surfaces. When specimens are carefully prepared, the results of this study show that the prism-type specimens (type *C*) afford satisfactory test results.

Purpose

The prism-shaped laterally supported plywood compression specimens used to determine the compressive strength properties of thin plywood, as described in A.S.T.M. Tentative Methods of Testing Veneer, Plywood, and Other Wood and Wood-Base Materials (D 805 - 44 T),[2] generally show a tendency to fail by buckling in the

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* Also published in ASTM Bulletin, No. 133, March, 1945, p. 33.

[1] Engineer, Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] 1944 Book of A.S.T.M. Standards, Part II, p. 1453.

short length that must necessarily extend beyond the lateral supports. In addition, they require good fabrication to avoid chipped and frayed ends. The purpose of this investigation was, therefore, twofold: (1) to compare the strength properties of the prism form of specimen (type *C*) with those of two forms of hourglass specimens (types *A* and *B*) (Fig. 1) to determine whether or not the mode of failure was also reflected in the strength properties obtained from the different forms of specimens when all specimens were well fabricated; and (2) to compare the properties obtained from type *B* and type *C* specimens when the ends were deliberately chipped and frayed, as might be produced by poor fabrication.

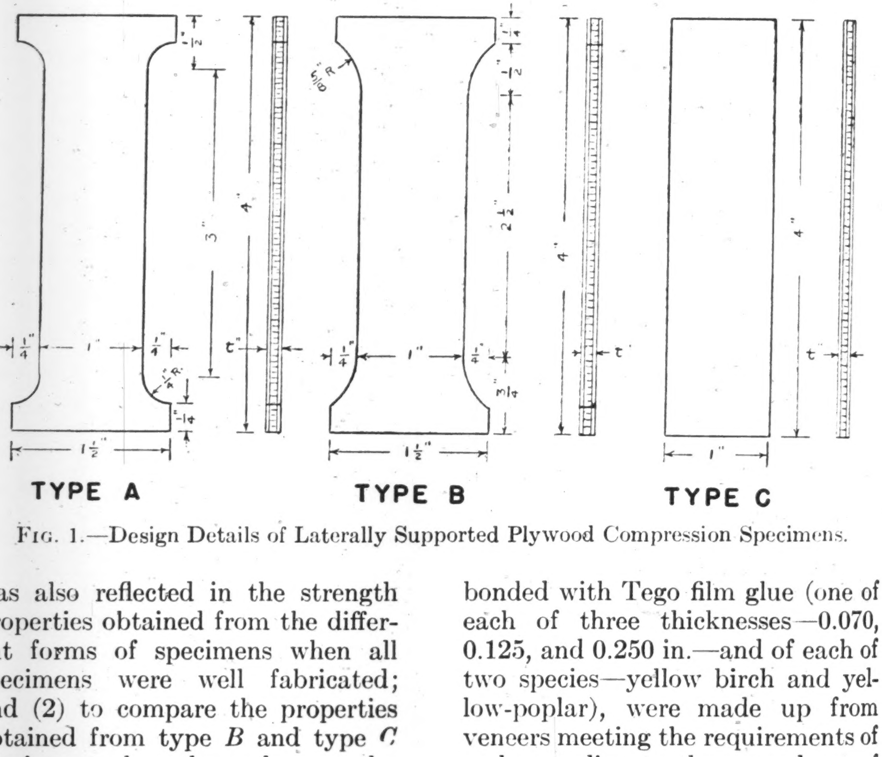

FIG. 1.—Design Details of Laterally Supported Plywood Compression Specimens.

SCOPE

The data presented show comparative results based on tests made on the three different types of specimens for each of two species and three plywood thicknesses of each species, all prepared in the normal manner with smooth end surfaces. Comparable data are also included based on tests of types *B* and *C* specimens of one plywood species and thickness, poorly sawn with the resultant frayed ends.

DESCRIPTION OF MATERIAL

Six 24 by 24-in. plywood panels, bonded with Tego film glue (one of each of three thicknesses—0.070, 0.125, and 0.250 in.—and of each of two species—yellow birch and yellow-poplar), were made up from veneers meeting the requirements of and according to the procedures of Army-Navy Aeronautical Specification Plywood and Veneer; Aircraft Flat Panel, AN-NN-P-511b.

MATCHING AND MARKING

Each of the six plywood panels was sawn to obtain a set of specimens of each type, ten specimens to a set. The specimens of a given set were cut out side by side across the grain of the face plies, with the grain of the face plies parallel to the length of the specimen, and the three sets were end matched. The specimens were numbered consecutively from 1 to 10, and specimens of a given species and thickness and the same specimen number were directly end matched. The hourglass specimens (types *A* and *B*) were cut to shape (Fig. 1) using a template in conjunction with a vertical-spindle woodworking shaper. In addition, two sets of specimens were prepared from the 0.125-in. birch plywood to study the effect of torn ends on the specimen properties. After preparation, all specimens were conditioned to constant weight in a room maintained at 75 F. and 64 per cent relative humidity.

METHOD OF TEST

The individual specimens were weighed and measured and then tested in accordance with the procedure outlined in A.S.T.M. Methods D 805 for compression tests on material $\frac{3}{4}$ in. in thickness. The tests were conducted in a room in which the temperature and humidity were controlled to 75 F. and 64 per cent relative humidity, respectively. The type of failure for each type of specimen was noted, and the complete specimen was then used for a determination of moisture content.

PRESENTATION OF DATA

The summation of comparative strength properties of the various specimen types for all plywood thicknesses of both species is pre-

TABLE I.—COMPARATIVE STRENGTH PROPERTIES OF PRISM-SHAPED (TYPE *C*) AND HOURGLASS (TYPES *A* AND *B*) LATERALLY SUPPORTED PLYWOOD COMPRESSION SPECIMENS.

Specimen Type	Moisture Content, per cent	Maximum Crushing Strength, psi.	Fiber Stress at Proportional Limit, psi.	Modulus of Elasticity, psi.
Yellow Birch 0.070-in. Three-Ply Plywood				
A Max.	8.1	6080	4820	1 440 000
Min.	7.6	5550	3720	1 310 000
Avg.	7.8	5820	4190	1 360 000
B Max.	8.6	6010	4780	1 360 000
Min.	7.7	5560	3640	1 240 000
Avg.	8.2	5860	4030	1 310 000
C Max.	8.5	6390	4040	1 540 000
Min.	7.8	5630	3460	1 190 000
Avg.	8.2	6070	3790	1 400 000
Yellow Birch 0.125-in. Three-Ply Plywood				
A Max.	8.7	6130	3930	1 390 000
Min.	8.2	5560	3340	1 270 000
Avg.	8.5	5880	3630	1 320 000
B Max.	8.6	5920	4660	1 460 000
Min.	8.2	5480	3200	1 270 000
Avg.	8.4	5690	3770	1 340 000
C Max.	8.4	6590	4700	1 400 000
Min.	7.8	5960	3710	1 310 000
Avg.	8.0	6210	4110	1 360 000
Yellow Birch 0.250-in. Five-Ply Plywood				
A Max.	8.6	5620	3460	1 250 000
Min.	8.3	5190	2900	1 100 000
Avg.	8.4	5370	3190	1 180 000
B Max.	8.9	5580	3360	1 300 000
Min.	8.1	5270	2740	1 180 000
Avg.	8.5	5430	3080	1 230 000
C Max.	8.2	5560	3720	1 330 000
Min.	7.8	5300	2900	1 170 000
Avg.	8.0	5440	3370	1 260 000
Yellow-Poplar 0.070-in. Three-Ply Plywood				
A Max.	7.7	5020	4180	1 320 000
Min.	5.9	4460	3050	1 110 000
Avg.	7.1	4700	3680	1 200 000
B Max.	8.3	5340	4490	1 310 000
Min.	7.8	4520	3660	1 020 000
Avg.	8.1	4980	3970	1 170 000
C Max.	8.8	5220	4350	1 330 000
Min.	7.3	4530	3380	1 190 000
Avg.	7.6	4900	3840	1 260 000
Yellow-Poplar 0.125-in. Three-Ply Plywood				
A Max.	8.3	3780	2450	910 000
Min.	7.2	3250	2090	740 000
Avg.	7.9	3440	2220	800 000
B Max.	8.2	3950	2700	995 000
Min.	7.8	3160	2080	730 000
Avg.	8.0	3470	2300	840 000
C Max.	7.7	3870	2770	965 000
Min.	7.4	3340	1890	810 000
Avg.	7.6	3590	2280	880 000
Yellow-Poplar 0.250-in. Five-Ply Plywood				
A Max.	7.7	3540	2880	910 000
Min.	7.3	3110	1850	755 000
Avg.	7.6	3240	2120	825 000
B Max.	7.9	3520	2570	915 000
Min.	7.5	2900	1840	705 000
Avg.	7.8	3190	2050	810 000
C Max.	7.6	3640	2570	950 000
Min.	6.9	2870	1850	760 000
Avg.	7.2	3260	2190	855 000

sented in Table I. Included therein are the moisture content values for the test specimens, which afford an indication of the uniformity of the conditioning treatment and permit proper evaluation of the strength results, since each of these varies with moisture content. The strength properties at ultimate and proportional limit and the modulus of elasticity values for each specimen group are tabulated.

Specific gravity values based on volume at test and weight when oven-dry indicated that the plywood of a given thickness was fairly uniform in density. The birch plywood averaged 0.68, 0.68, and 0.65 and the yellow poplar plywood 0.54, 0.46, and 0.43 for the 0.070-, 0.125-, and 0.250-in. plywood thicknesses, respectively.

TABLE II.—COMPARATIVE COMPRESSIVE STRENGTH PROPERTIES OF POORLY FABRICATED, PRISM-SHAPED SPECIMENS AND HOURGLASS-SHAPED SPECIMENS LATERALLY SUPPORTED. SPECIMENS WERE $^{1}/_{8}$-IN. YELLOW BIRCH PLYWOOD.

Specimen Type	Moisture Content, per cent	Maximum Crushing Strength, psi.	Fiber Stress at Proportional Limit, psi.	Modulus of Elasticity, psi.
B Max.	9.3	5840	4570	1 410 000
Min.	8.6	5380	3660	1 160 000
Avg.	9.0	5620	4030	1 280 000
C Max.	8.7	5360	4510	1 350 000
Min.	8.3	4890	3490	1 180 000
Avg.	8.6	5180	4060	1 280 000

Table II presents a similar tabulation of data for the supplementary test series to show the effect of frayed ends on test results.

Typical specimens are shown in Figs. 2 and 3. Figure 2 shows typical failures for each of the specimen types, and Fig. 3 permits a visual comparison of good and bad end conditions.

ANALYSIS OF RESULTS

Since the material was conditioned and tested in a room in which the temperature and humidity were controlled, the moisture content variation within a species thickness group was, in general, small; and, since an adjustment of strength values for moisture content differences of $\frac{1}{2}$ per cent or less is not justified, the actual test results may be compared without material error.

The variation of the values of average ultimate compressive strength and modulus of elasticity within each species thickness group was, in most instances, 5 per cent or less, and the maximum variation was 9 per cent. Although the proportional limit values are normally more variable and a somewhat greater spread in results was anticipated, the maximum variation was 12 per cent, and it was generally closer to half of that value. In the majority of tests, the prism-shaped specimens gave the highest average results for both compressive strength and modulus of elasticity, although, as previously mentioned, the differences were not large. It is believed that the modulus of elasticity values were less for the hourglass specimens because of the restraining action of the added material. In the use of such specimens, it appears necessary to use a somewhat longer specimen or shorter gage length compressometer to eliminate this effect.

The close agreement of results was obtained despite marked differences in type of failure, as shown in Fig. 2. The prism-shaped specimen (type *C*) in the 0.070- and 0.125-in. plywood thicknesses failed more than 90 per cent of the time by buckling in the short length of specimen above the lateral supports. In the 0.250-in. plywood, this type of failure occurred in approximately half of the cases. The failures in the hourglass specimens (types *A* and *B*) were, in practically all instances, normal compression failures (shear type) occurring in the net section of the specimen.

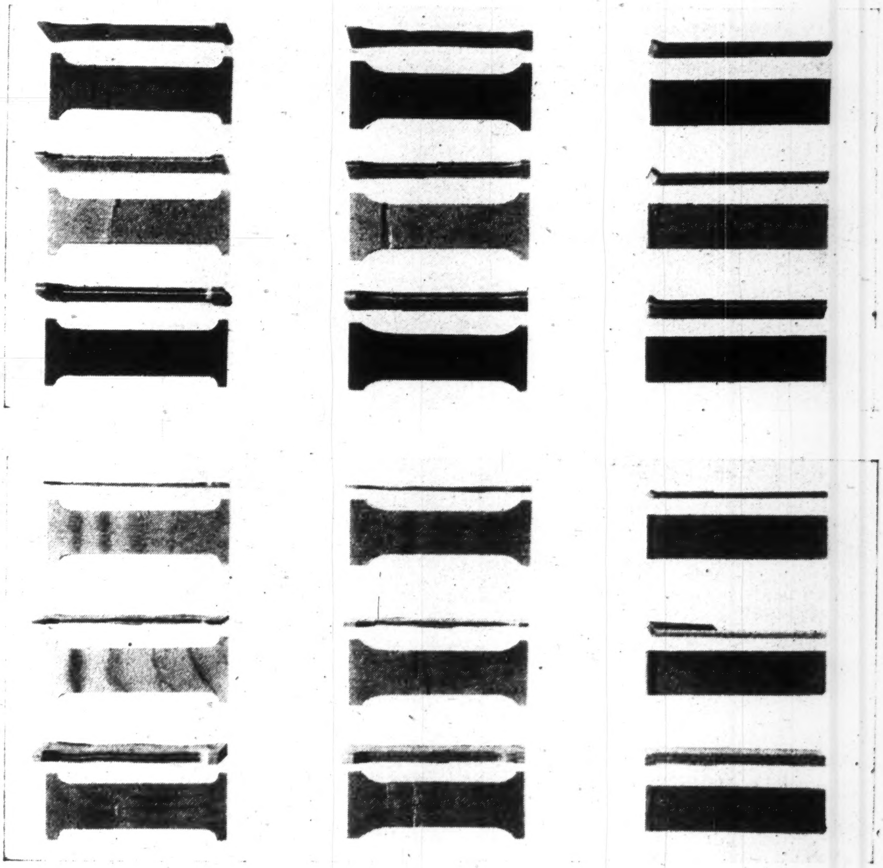

FIG. 2.—Typical Failures Obtained on Three Types of Laterally Supported Plywood Compression Specimens of Two Species and Three Thicknesses.

Type *A*, left; type *B*, center; type *C*, right.

The data presented in Table II provide an indication of results obtained from improperly prepared specimens having chipped and torn ends. These data are based on tests of 0.125-in. yellow birch plywood and may be compared with the results secured on well-prepared specimens given in Table I. Both specimen types in this series show only slight changes for values of fiber stress at proportional limit and modulus of elasticity as compared with the values in Table I. The prism-shaped specimen (type *C*), however, shows a 10 per cent decrease in ultimate compressive strength; whereas this decrease is only slight for the type-*B* specimens. It is apparent, therefore, that specimens must be properly prepared to secure good test results. Since the type *C* specimen is much easier to prepare, it is the most simple to use for this type of test, provided that proper consideration is given to secure satisfactory specimens.

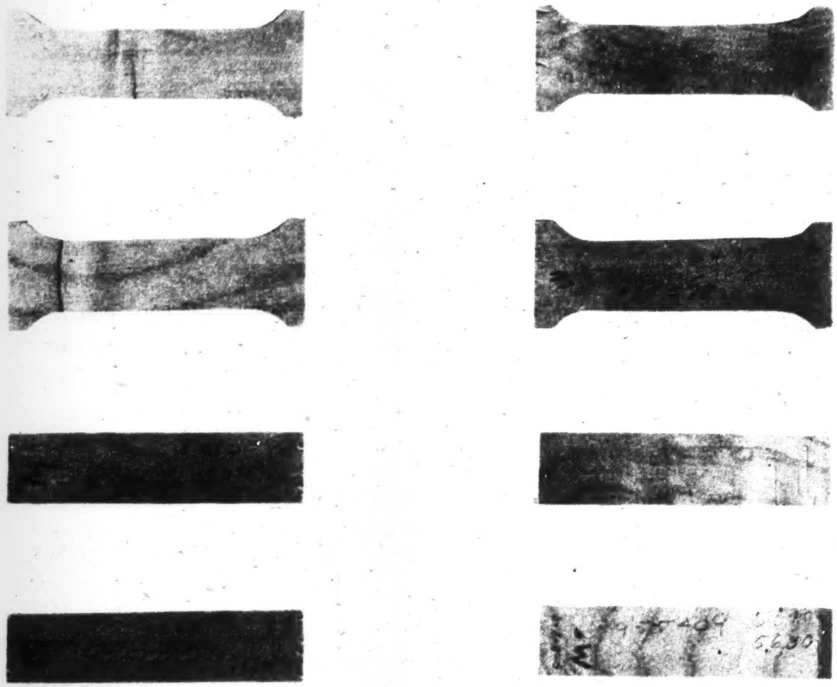

FIG. 3.—Example of Good and Bad Methods of Specimen Preparation, Showing the Chipped and Frayed Ends Which Result on Type *B* (top, left) and Type *C* (bottom, left) Specimens When Insufficient Care Is Taken In Their Fabrication.

Although the differences in mean values obtained for the various physical properties from each of the specimen types within a species-thickness group were usually small, it was decided to determine whether or not these differences were significant. Therefore, a statistical analysis was made on the data to obtain results on significant differences between specimen-type means for each property in each species-thickness group, and a summary of this analysis is included in Table III of the Appendix. In general, the analysis indicated that the mean compressive stress obtained on type *C* specimens was significantly greater than that obtained on specimens of either type *A*, type *B*, or both at the 1 per cent level for the 0.070- and 0.125-in. plywood of both species. Likewise, the mean values of the modu-

TABLE III.—SUMMARY OF SIGNIFICANT DIFFERENCES BETWEEN SPECIMEN TYPE MEANS FOR THE STRENGTH PROPERTIES OF PRISM-SHAPED (TYPE *C*) AND HOUR-GLASS (TYPES *A* AND *B*) LATERALLY SUPPORTED PLYWOOD COMPRESSION SPECIMENS.

Plywood		Specimen Type	Significant Difference
Species	Thickness, in.		
			MAXIMUM COMPRESSIVE STRESS
Yellow birch....	0.070	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *A* and *B* at 1 per cent level
	0.125	A	Significantly greater than *B* at 5 per cent level
		B	....
		C	Significantly greater than *A* and *B* at 1 per cent level
	0.250	A	No significant difference
		B	No significant difference
		C	No significant difference
			FIBER STRESS AT PROPORTIONAL LIMIT
Yellow birch....	0.070	A	Significantly greater than *C* at 5 per cent level (but not than *B*)
		B	No significant difference between *B* and *C*
		C	....
	0.125	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *B* at 5 per cent level—significantly greater than *A* at 1 per cent level
	0.250	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *B* at 5 per cent level (but not than *A*)
			MODULUS OF ELASTICITY
Yellow birch....	0.070	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *B* at 1 per cent level (but not than *A*)
	0.125	A	No significant difference
		B	No significant difference
		C	No significant difference
	0.250	A	....
		B	No significant difference between *B* and *C*
		C	*C* and *B* are significantly greater than *A* at 1 per cent leve
			MAXIMUM COMPRESSIVE STRESS
Yellow-poplar...	0.070	A	....
		B	No significant difference between *B* and *C*
		C	*C* and *B* are significantly greater than *A* at 1 per cent level
	0.125	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *A* at 5 per cent level (but not than *B*)
	0.250	A	No significant difference
		B	No significant difference
		C	No significant difference
			FIBER STRESS AT PROPORTIONAL LIMIT
Yellow-poplar...	0.070	A	No significant difference between *A* and *C*
		B	Significantly greater than *A* at 5 per cent level (but not than *C*)
		C	....
	0.125	A	No significant difference
		B	No significant difference
		C	No significant difference
	0.250	A	No significant difference
		B	No significant difference
		C	No significant difference
			MODULUS OF ELASTICITY
Yellow-poplar...	0.070	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *A* at 5 per cent level—significantly greater than *B* at 1 per cent level
	0.125	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *B* at 5 per cent level—significantly greater than *A* at 1 per cent level
	0.250	A	No significant difference between *A* and *B*
		B	....
		C	Significantly greater than *A* at 5 per cent level—significantly greater than *B* at 1 per cent level
			FRAYED-END SPECIMENS
Yellow birch....	0.125	B	Significantly greater than *C* at 1 per cent level (maximum compressive stress)
	0.125	B	No significant difference between *B* and *C* (fiber stress at proportional limit)
	0.125	B	No significant difference between *B* and *C* (modulus of elasticity)

lus of elasticity for type *C* were significantly greater than those for the other two types. More variation was encountered in the analysis of the values of proportional limit stress because of the personal equation involved in their evaluation. It was apparent, however, that when the specimen ends were frayed, the maximum crushing strength for the type *B* specimens was significantly greater than that for specimens of type *C*.

CONCLUSIONS

Although the characteristic mode of failure of the prism-shaped specimen (type *C*) differed from that of the hourglass specimens (types *A* and *B*), the results of this program indicated that these three types of laterally supported plywood compression specimens give essentially the same results, with the prism-shaped specimens (type *C*) giving the slightly higher values. This assumes that the specimens are carefully prepared so that their ends are smooth, parallel to each other, and perpendicular to their lengths.

If the specimens have poorly cut ends and the plywood faces are torn, the prism-shaped specimen (type *C*) will give markedly lower ultimate compressive strength values. The hourglass specimens (type *B*) are more satisfactory if this condition exists.

When specimens are carefully prepared, the prism-shaped specimens (type *C*) afford satisfactory test results, and because of its shape, it is the most simple one to use for this type of test. In its preparation proper care should be exercised to insure smooth end surfaces.

APPENDIX

The results of a statistical analysis of the test results on the three types of specimens of each of the two species are given in Table III. This table presents a summary of the significant differences between specimen type means for the strength properties of the prism-shaped (type *C*) and hourglass (types *A* and *B*) laterally supported plywood compression specimens. It also gives significant differences for the test results obtained on frayed end specimens of types *B* and *C*. Although the analysis may be slightly clouded because the selection of specimens was not truly randomized, it is believed that the conclusions based on the analysis are pertinent.

A NEW MACHINE FOR MEASURING WEAR RESISTANCE OF WALKWAY MATERIALS[1] *

By A. W. Cizek, Jr.,[2] D. H. Kallas,[2] and H. Nestlen[2]

Resistance to wear is one of the most important functional properties of walkway materials and is the most difficult to evaluate by laboratory methods. The authors have attempted to develop a laboratory machine and method with the view that rapid and duplicable determination of wear resistance will be of great commercial and scientific value and will lead to the development of more durable walkway materials.

Wear resistance may be defined as the ability of a material to resist the progressive wearing away of its exposed surface by rubbing action. Machines incorporating various mechanical actions to produce wear have yielded satisfactory results and are currently in use on certain phases of the problem of wear resistance. In general, however, it has been difficult to build equipment which would give satisfactory comparative data for the evaluation of materials of different composition.

The principal difficulty in the development of a suitable machine lies in the fact that wear is not caused by one factor, but is the effect of many variable factors such as impact, sliding, scuffing, and rubbing, all in the presence of an abrasive. The problem of wear becomes even more involved when it is noted that some of these factors may be present in one case and entirely absent in another. It is evident, therefore, that wear resistance is a complex property and varies according to the particular service to which a material is subjected. Any machine which attempts to measure indiscriminately the wear resistance of all kinds of materials subjected to all conditions of wear is based on the premise that wear resistance is independent of the factors involved. This is an erroneous supposition and can only lead to false conclusions.

In view of the foregoing, the authors have limited themselves to the development of a machine which will be primarily a wear test machine for determining the resistance of walkway materials to wear. Of course, as frequently happens, apparatus developed for one purpose can be and is successfully used for related work, and it is neither the intention nor the desire of the authors to restrict the application of this apparatus. However, as has been indicated earlier in this paper, it is not considered that the solution of the wear resistance problem is limited to one method or one type of apparatus. The applicability of the authors' machine is entirely dependent on the similarity of the factors influencing wear with those which were investigated during the development of the machine described herein.

The first step in the development of a suitable apparatus was, by necessity, a rational analysis of the conditions of wear which were to be expected on

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[1] The opinions or assertions contained herein are the private ones of the writers and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.

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walkway materials. As it was recognized that wear resistance was a complex property and would have to be investigated for the specific condition in mind, a study of the wear of walkway materials was made. The presence of the following basic factors was found to be essential for a satisfactory solution of the problem.

1. Sliding of the test surface against another surface.

2. Impact of the test surface with another surface.

3. Continual reversal of direction of motion between test surface and another surface.

4. The presence of abrasive particles between the test surface and another surface.

5. Random motion of the abrasive particles.

The above factors having been established, the analysis of the problem could now be continued to its conclusion. However, although the rational analysis outlined above may have been extended further to include quantitative criteria limiting the above factors, it was considered that a continuation of the analysis on an empirical rather than a rational basis would be more desirable, particularly from the viewpoint of machine design and expedience. On the basis of preliminary experiment and test data, it was therefore decided that the factors enumerated above should be modified as follows:

(*a*) The surface against which the test material moves should be of steel.

(*b*) The specimen should be dropped through a distance of $\frac{1}{16}$ in. to effect the impact.

(*c*) The abrasive particles should be of the same material and grit size.

(*d*) The abrasive particles should be continually replaced at a constant rate.

(*e*) The abrasive particles should be cleaned and screened before being used.

(*f*) The specimen test area should be a 2 by 3-in. rectangle.

(*g*) The total load on the specimen should be 10 lb.

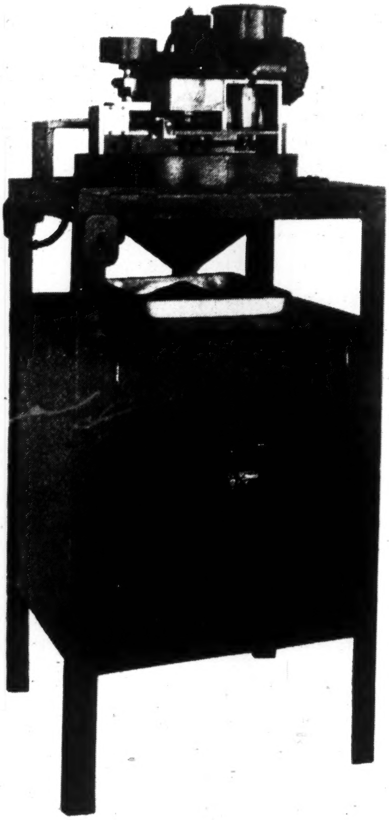

FIG. 1.—Wear Test Machine.

(*h*) The relative velocity between the test material and surface should be reasonably low to avoid heating effects.

APPARATUS

The abrasive wear test machine as illustrated by Figs. 1 and 2 consists of the following parts:

A = Abrasion disk, mild steel, $14\frac{1}{8}$ in. in diameter and $\frac{1}{2}$ in. thick, revolved clockwise at a constant speed of 23.5 rpm.

B = Specimen holder, 2 by 4 in., attached to a $\frac{5}{8}$-in. diameter shaft by means of a universal coupling. A specimen of the material under test is secured in the specimen holder by means of clamps at each end of the holder. The holder revolves clockwise at a constant speed of 32.5 rpm.

C = Cam follower attached to the specimen holder shaft by means of set-screws. In each $\frac{1}{2}$ revolution of the specimen holder shaft, the specimen is momentarily lifted a distance of $\frac{1}{16}$ in. and dropped back on disk A under a 10-lb. weight, as the cam follower rides on a hardened tool steel cam. Change in the lift due to wear of the specimen is compensated by adjustment of the cam follower at regular intervals, so that the lift is maintained at a practically constant distance.

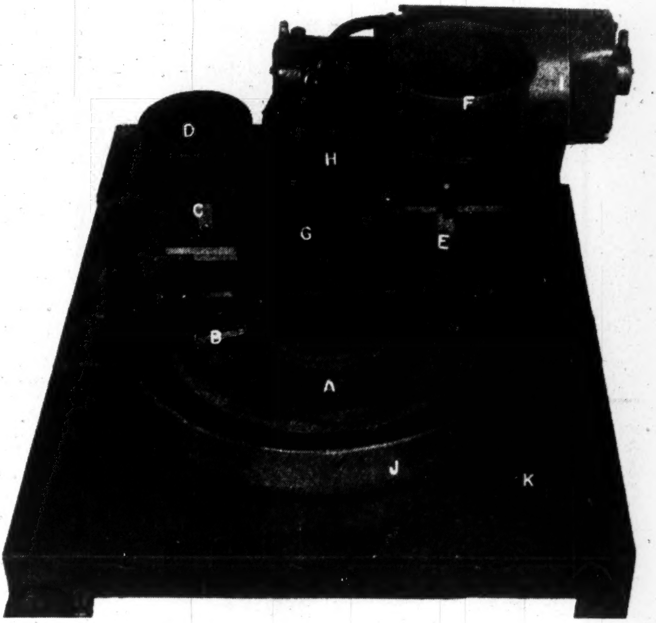

FIG. 2.—Detail View of Wear Test Machine.

D = Weight, 10 lb. acting on specimen.

E = Distributor for abrasive grits, as shown in detail by Figs. 4 and 5, consists of the following parts:
  a = Grit distributor sprocket.
  b = Grit distributor casing.
  c = Diaphragm perforated with eight $\frac{3}{64}$-in. diameter holes, centered on a $1\frac{5}{8}$-in. diameter pitch circle.
  d = Grit conveying tube and agitator.

The grit flows by gravity from the hopper F through a $\frac{13}{64}$-in. inside diameter conveying tube into the center of the distribution chamber. The agitator feeds the grit from the center of the distribution chamber outward to the holes in the perforated diaphragm. The grit then falls through the holes to disk A in the path of the test specimen, at a rate of approximately 44 g. per minute. It is notable that the grit conveying

tube and agitator are stationary, and the grit distributor casing is revolved by sprocket *d* at a constant speed of 9 rpm.
F = Hopper for feeding abrasive grit.
G = Bevel drive gear.
H = Predetermining revolution counter and switch.
I = $\frac{1}{3}$-hp. compound wound d-c. motor.
J = Hopper for collecting used abrasive grit.
K = Steel frame.

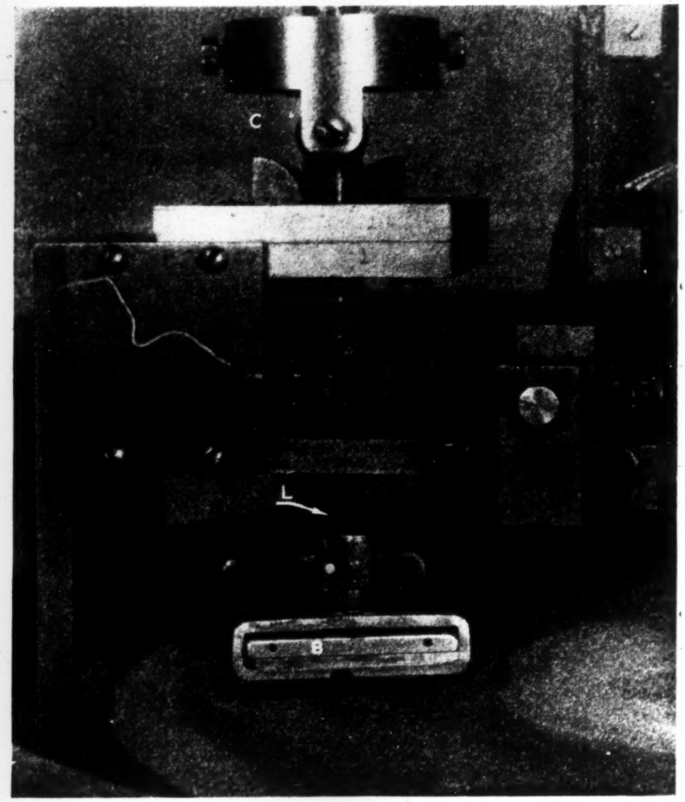

FIG. 3.—Detail of Cam and Specimen Holder.

The abrasive grit consists of No. 80 aluminum oxide, which is washed, dried, and screened before being placed into the hopper *F*. The size of the test specimen is 2 by 3 in., and the thickness and other details vary according to materials, as follows:

(*a*) Wood and mastic walkway materials.—Specimen $\frac{1}{4}$ in. thick attached to a 2 by 4 by $\frac{1}{8}$-in. thick steel plate, leaving $\frac{1}{2}$ in. of plate exposed at each end.

(*b*) Light-weight walkway materials. —The coating is troweled or sprayed to a thickness of approximately $\frac{1}{32}$ in. on a 2 by 3-in. raised portion of a 2 by 4 by $\frac{1}{4}$-in. thick steel plate, leaving $\frac{1}{2}$ in. of plate exposed at each end.

(*c*) Linoleum.—The linoleum is attached with linoleum cement to a 2 by 3-in. raised portion of a 2 by 4 by $\frac{1}{4}$-in. thick steel plate leaving $\frac{1}{2}$ in. of plate exposed at each end.

The specimen is clamped to the $\frac{1}{2}$-in. wide exposed surface of the specimen holder *B* which is connected to the $\frac{5}{8}$-in. diameter shaft by means of the universal coupling *L* (see Fig. 3).

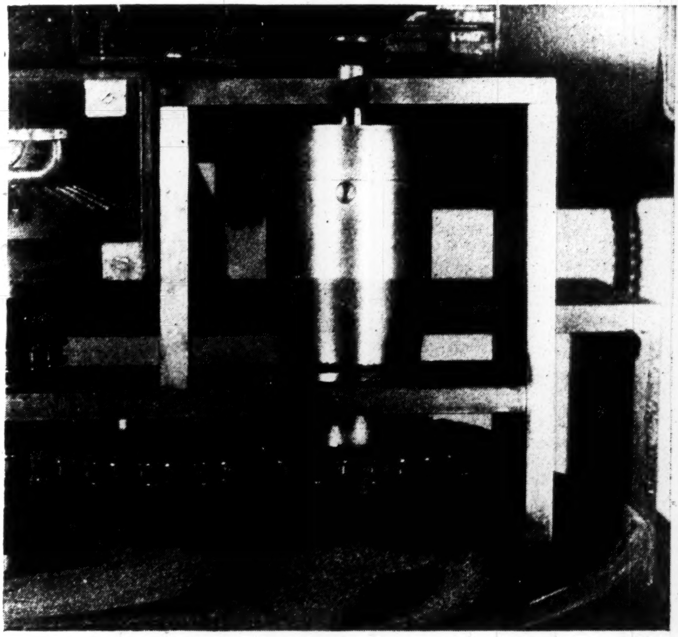

FIG. 4.—Detail of Distributor of Abrasive Grit.

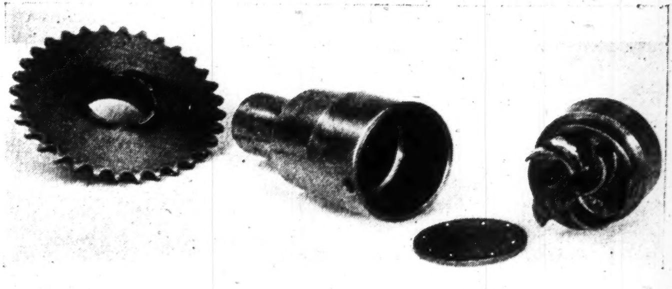

FIG. 5.—Disassembled Distributor of Abrasive Grit.

METHOD OF TEST

Tests were made in the above machine to determine the rate of wear on 20 specimens of each of the following walkway materials, obtained from Naval stores:

Teak wood.
Battleship linoleum (Navy Dept. Spec. LLL-L-351a).
Light-weight walkway material (Navy Dept. Spec. 52D9).

NOTE.—The light-weight walkway material consists primarily of a resinous vehicle with pigments and a considerable proportion of fine abrasive particles employed to give the coating anti-slip and wear-resistant properties. The material is furnished in consistencies suitable for application either by troweling or by spraying.

The wear was determined by measuring the difference in thickness of the specimen before and after a given number of revolutions of disk *A* on the wear test machine. The teak wood and linoleum were tested for a total of 1500 revolutions, thickness measurements being taken after each 500 revolutions.

TABLE I.—TEAK WOOD.

	Specimen	Wear, in.		
Number of revolutions........		0 to 500	500 to 1000	1000 to 1500
First Operator.....	No. 1	0.0414	0.0410	0.0418
	No. 2	0.0379	0.0395	0.0388
	No. 3	0.0381	0.0368	0.0402
	No. 4	0.0407	0.0410	0.0393
Second Operator...	No. 5	0.0397	0.0448	0.0454
	No. 6	0.0409	0.0435	0.0415
	No. 7	0.0420	0.0416	0.0439
	No. 8	0.0428	0.0359	0.0364
Third Operator....	No. 9	0.0407	0.0412	0.0430
	No. 10	0.0376	0.0340	0.0322
	No. 11	0.0403	0.0392	0.0399
	No. 12	0.0443	0.0456	0.0446
Fourth Operator...	No. 13	0.0426	0.0439	0.0436
	No. 14	0.0505	0.0511	0.0500
	No. 15	0.0350	0.0355	0.0342
	No. 16	0.0519	0.0515	0.0471
Fifth Operator.....	No. 17	0.0450	0.0445	0.0450
	No. 18	0.0433	0.0450	0.0448
	No. 19	0.0425	0.0431	0.0449
	No. 20	0.0519	0.0507	0.0531
General average..........		0.0425	0.0425	0.0425
Average total amount of wear............				0.1275
Standard deviation........		0.0044	0.0049	0.0049
Final average[a]...........		0.0417	0.0426	0.0429
Final average total amount of wear......				0.1272
Maximum..............		0.0519	0.0515	0.0531
Minimum..............		0.0350	0.0340	0.0322
Number of readings omitted by means of the first standard deviation to determine the final average		6	7	5

[a] Final average determined by elimination of high and low readings with first standard deviation.

The light-weight walkway material was tested for a total of 100 revolutions, thickness measurements being taken after each 25 revolutions. The thickness of the specimens tested was taken as the average of 12 measurements made by means of a dial thickness gage at locations on a template used for all specimens. Tests were made only on the materials "as received," that is, without exposure to any conditions of aging and with specimen and disk in a dry condition. In order to take account of personal element in conducting the tests, each of five individuals tested a separate lot of four specimens of each type of walkway material.

RESULTS OF TEST

The results of test are given in Tables I, II, and III, and the plotted averages are shown in Figs. 6 and 7.

TABLE II.—LINOLEUM.

	Specimen	Wear, in.		
Number of revolutions........		0 to 500	500 to 1000	1000 to 1500
First Operator.....	No. 1	0.0073	0.0041	0.0073
	No. 2	0.0074	0.0055	0.0060
	No. 3	0.0058	0.0065	0.0049
	No. 4	0.0061	0.0065	0.0045
Second Operator...	No. 5	0.0121	0.0068	0.0022
	No. 6	0.0018	0.0098	0.0067
	No. 7	0.0064	0.0051	0.0048
	No. 8	0.0062	0.0058	0.0050
Third Operator....	No. 9	0.0106	0.0076	0.0059
	No. 10	0.0053	0.0051	0.0061
	No. 11	0.0063	0.0050	0.0034
	No. 12	0.0060	0.0059	0.0008
Fourth Operator...	No. 13	0.0075	0.0044	0.0035
	No. 14	0.0081	0.0054	0.0046
	No. 15	0.0029	0.0069	0.0049
	No. 16	0.0020	0.0060	0.0050
Fifth Operator.....	No. 17	0.0041	0.0044	0.0065
	No. 18	0.0069	0.0041	0.0046
	No. 19	0.0075	0.0059	0.0053
	No. 20	0.0060	0.0064	0.0052
General average..........		0.0063	0.0059	0.0049
Average total amount of wear...........				0.0171
Standard deviation........		0.0024	0.0013	0.0014
Final average[a]...........		0.0065	0.0059	0.0052
Final average total amount of wear......				0.0176
Maximum...............		0.0121	0.0096	0.0073
Minimum...............		0.0018	0.0041	0.0022
Number of readings omitted by means of the first standard deviation to determine the final average		5	6	5

[a] Final average determined by elimination of high and low readings with first standard deviation.

CONCLUSIONS

The results of tests as outlined in Tables I, II, and III for the resistance to wear of teak wood, linoleum and light-weight walkway material indicate that although the rate of wear varies in the same specimen as well as between specimens of any of the materials tested, the percentage of total observations lying within given ranges compares favorably with the theoretical estimated percentages specified by the A.S.T.M.[3]

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[3] A.S.T.M. Manual on Presentation of Data, August, 1940. (Issued as separate publication.)

for data obtained under controlled conditions (see Table IV). It is, therefore, considered that the wear test machine offers a satisfactory method for evaluating the wear of walkway materials.

Although the wear test machine described in this paper is not proposed as a universal solution for the problem of wear resistance, it is believed that its use, as discussed above, can be successfully extended to almost all walkway materials and to other materials which are subjected to similar conditions of wear. In this connection, the wear test

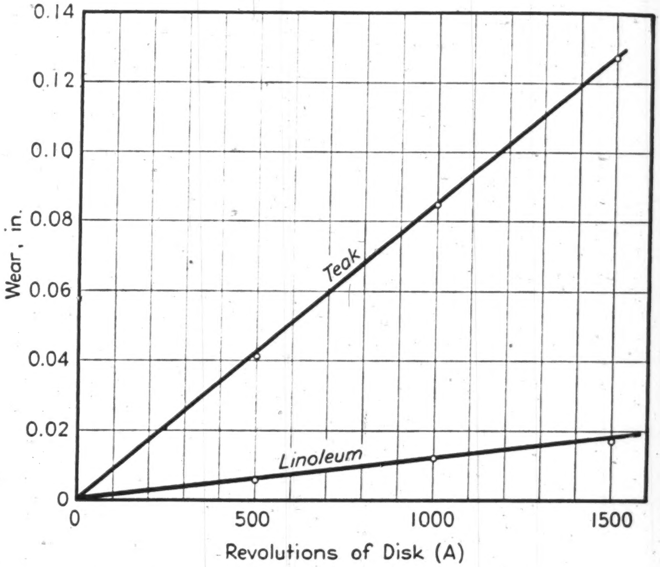

FIG. 6.—Results of Tests on Wear Test Machine.

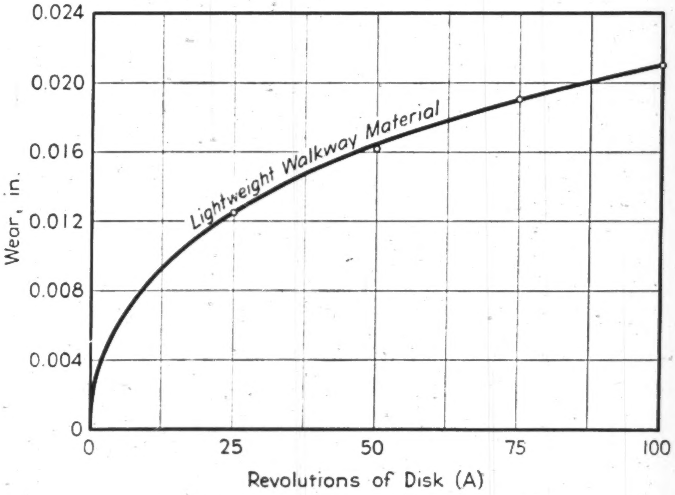

FIG. 7.—Results of Tests on Wear Test Machine.

machine in its present form offers a high degree of versatility in so far as the factors such as speed, amount of lift of specimen, amount of abrasive, size and kind of abrasive, material on the face of the abrasion disk, ratio of specimen shaft speed to abrasion disk speed, size of the specimen, configuration of the specimen and load on the specimen can be varied independently to give the combination of conditions most closely approximating actual service.

TABLE III.—LIGHT-WEIGHT WALKWAY MATERIAL.

	Specimen	Wear, in.			
Number of revolutions		0 to 25	25 to 50	50 to 75	75 to 100
First Operator	No. 1	0.0123	0.0041	0.0024	0.0017
	No. 2	0.0138	0.0046	0.0028	0.0014
	No. 3	0.0127	0.0041	0.0021	0.0022
	No. 4	0.0135	0.0036	0.0022	0.0012
Second Operator ...	No. 5	0.0100	0.0040	0.0033	0.0035
	No. 6	0.0129	0.0028	0.0025	0.0024
	No. 7	0.0131	0.0026	0.0033	0.0021
	No. 8	0.0136	0.0048	0.0026	0.0023
Third Operator	No. 9	0.0122	0.0030	0.0029	0.0024
	No. 10	0.0110	0.0040	0.0030	0.0022
	No. 11	0.0138	0.0035	0.0032	0.0026
	No. 12	0.0096	0.0061	0.0023	0.0028
Fourth Operator ...	No. 13	0.0121	0.0042	0.0024	0.0015
	No. 14	0.0128	0.0035	0.0031	0.0006
	No. 15	0.0141	0.0042	0.0049	0.0035
	No. 16	0.0135	0.0034	0.0019	0.0013
Fifth Operator	No. 17	0.0136	0.0029	0.0021	0.0017
	No. 18	0.0103	0.0046	0.0031	0.0019
	No. 19	0.0129	0.0023	0.0029	0.0019
	No. 20	0.0126	0.0021	0.0024	0.0013
General average		0.0125	0.0037	0.0028	0.0020
Average total amount of wear					0.0210
Standard deviation		0.0013	0.0009	0.0006	0.0007
Final average[a]		0.0130	0.0038	0.0028	0.0019
Final average total amount of wear					0.0215
Maximum		0.0141	0.0048	0.0049	0.0035
Minimum		0.0096	0.0021	0.0019	0.0006
Number of readings omitted by means of the first standard deviation to determine the final average		5	5	4	5

[a] Final average determined by elimination of high and low readings with first standard deviation.

TABLE IV.—COMPARISON OF OBSERVED PERCENTAGES AND THEORETICAL ESTIMATED PERCENTAGES OF THE TOTAL OBSERVATION LYING WITHIN GIVEN RANGES.

Range, Average, X, plus or minus[a]	Estimated Percentage[b]	Observed Percentages			
TEAK					
		0 to 500 revolutions	500 to 1000 revolutions	1000 to 1500 revolutions	
1σ	68.3	70.0	65.0	75.0	
2σ	95.5	90.0	100.0	90.0	
3σ	99.7	100.0	100.0	100.0	
LINOLEUM					
		0 to 500 revolutions	500 to 1000 revolutions	1000 to 1500 revolutions	
1σ	68.3	75.0	70.0	75.0	
2σ	95.5	95.0	95.0	95.0	
3σ	99.7	100.0	100.0	100.0	
LIGHT-WEIGHT WALKWAY MATERIAL					
		0 to 25 revolutions	25 to 50 revolutions	50 to 75 revolutions	75 to 100 revolutions
1σ	68.3	75.0	75.0	80.0	75.0
2σ	95.5	95.0	95.0	95.0	85.0
3σ	99.7	100.0	100.0	95.0	100.0

[a] σ = standard deviation.

[b] Theoretical estimated percentages of total observations, as shown on Fig. 14 of A.S.T.M. Manual on Presentation of Data, August, 1940.

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DISCUSSION

Mr. J. R. Shank[1] (*by letter*).—It appears that the authors have developed a testing procedure that meets demands very well for walkway materials, particularly when the materials to be tested are similar in hardness to those described. It does not seem to be so well adapted to materials of the brittle, hard, heavy, earthy, granular types such as stones and cement products. The writer had some experience in trying to adapt the Dorry testing machine to this service for the hard materials. As a result of this experience he is of the opinion that the authors' basic factor, "(*a*) The surface against which the test material moves should be steel," does not well suit the testing of hard, walkway materials. The tests which the writer reported upon[2] were more indicative of the resistance of the material to the action of a jumper drill than to ordinary walkway abrasion. The addition of a rubber pad between the steel disk and the specimen gave results which were very different from those reported and which seemed to fall better in line with experience with marbles.

Inasmuch as the abrasive action on walkways is brought about through the action of rubber or leather shoe soles, it appears that any testing apparatus for resistance to abrasion must have a cushion somewhere between the test specimen and the platen carrying the abrasive. The authors have this cushion, in the cases of all three materials tested, in the materials themselves. Had they been testing marble this would not have been the case.

If the specimen and the platen are both hard and have large mass or inertia values, in comparison with the abrasive particle, the action of the particle is to drill into one or the other, or both, with every turnover of the more or less irregular particle. If the face of one or the other materials in contact with the abrasive particle is of such a nature as to allow the particle to penetrate it without drilling a piece out of it, then the action is more nearly like the action of a shoe sole with sand on it. A difficulty that arises then is that of accelerating the test and keeping down the cost of platen material sufficiently to make the test procedure practical.

The dropping of the specimen $\frac{1}{16}$ in. hardly seems important inasmuch as the impact of shoe soles on walkways is never great and is absorbed by the material of the sole, particularly when it is rubber or like rubber in its texture. If, however, the walkway is to be subjected to steel tired wheels or sliding metal shoes and is of a hard material, the factors (*a*) and (*b*) are both important and the Dorry test is well suited.

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[1] Assistant Director, Engineering Experiment Station, The Ohio State University, Columbus, Ohio.

[2] J. R. Shank, "A Wear Test for Flooring Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 35, Part II, p. 533 (1935).

EFFECT OF DIMENSIONS OF SPECIMENS UPON THE PRECISION OF STRENGTH DATA*

By John Tucker, Jr.[1]

Synopsis

Statistical theories on the strength of materials are applied in estimating the effects of change in a dimension of the specimen on the mean strength and on the dispersion of the strength within a group of like specimens. The weakest-link theory predicts the effects of an increase in the length of specimens subjected to tension, compression, flexure, or torsion and in the depth of specimens subjected to flexure. The strength-summation theory appears to predict reasonably well the effects of an increase in the cross-sectional areas of specimens subjected to tension or compression and of an increase in width of the flexural specimen. Analyses based on the statistical theories of strength and the results of some tests indicate that reliable measures of the strength and uniformity of the strength of concrete may be obtained by testing a larger number of specimens which are much smaller than those commonly used.

In a previous paper (**1**)[2] the author demonstrated that the dispersion of the compressive strengths (stress at failure) of specimens of a concrete varies inversely with the diameter and that, within certain limiting values of the length, both the compressive strengths and their dispersions will vary with the length of the specimens. The modulus of rupture and its standard deviation have also been shown (**2**) to vary with the dimensions of the beam, approximating the changes predicted by the statistical theory of strength.

It is the object of the paper to show how changes in dimensions of the test specimens affect the statistical information obtained and to show the relative number of specimens of two sizes which must be tested to obtain information of equal reliability. It is shown that by increasing the size of specimen the number of tests may be reduced. In using specimens of a smaller size there will be less precision in the individual test, but this may be counteracted by increasing the number of specimens. Test specimens in some cases would be limited to a size usually considered below that which is adequate. It is shown how such small specimens may be utilized to give adequate information.

In the study of the strength of materials, there are several hypotheses of the method of failure: maximum stress, maximum strain, maximum shear, constant energy of deformation, etc. Each of these theories has been of value in certain applications. Similarly, in the recently developed statistical theory of the strength of materials, different statistical hypotheses of failure have been suggested. There are two types of dimensional change, and the effect of each upon the strength characteristics is distinctly different. The first type is a change such as in the axial length of a tension test specimen, the second is a change such as in the cross-sectional area of a tension specimen, in each case all other dimensions of the specimens remaining the same. For specimens of one cross-section, as specifically illustrated by chains, in which the length of the specimen may be varied, the weakest-link theory seems entirely logical and irrefutable from physical considerations. However, when the lateral dimensions of the test specimen are varied, no particular statistical hypothesis is apparent. The author (1) postulated the "summation theory," whereas Weibull (3) assumed that the equivalent to the weakest-link theory prevailed. Obviously both cannot be correct; from test data on concrete compressive test cylinders, the summation theory appeared to be more nearly confirmed. The selection of the correct hypothesis in the statistical theory of strength depends upon our knowledge of the mechanism of failure of the material. This mechanism cannot be predicted *a priori;* possibly the best proof ever available for the surviving theory will be the check between predicted and test results. However, the statistical theory by either of the hypotheses correctly predicts the directions of changes in strength and in the scattering in strengths with changes in the dimensions of specimens.

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* Manuscript received too late for general distribution before publication in *Proceedings*. Any additional discussion that is received for this paper will be published in the ASTM Bulletin and the 1946 *Proceedings*.

[1] Chief, Cement and Concreting Materials Section, National Bureau of Standards, Washington 25, D. C.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 959.

In this paper it is assumed that changes in length of specimens affect the strength dispersion of strength according to the weakest-link theory, and changes in lateral dimensions according to the summation theory. The latter was chosen because the limited available data indicate its applicability. It is assumed that the changes in dimensions are not accompanied by significant changes in the properties of the materials in the specimens; obviously the predictions of the theories would not be fulfilled otherwise.

When comparing strength data for specimens of like materials but of different size it is assumed that for the smallest test specimens the distribution of the strengths is normal. When the strength distribution is skew, the computed effects of variation of specimen dimensions will not usually be sufficiently different from those given in this paper to cause concern.

EFFECT OF CHANGE IN LENGTH OF SPECIMEN (WEAKEST-LINK THEORY)

Tension:

If the length of tension test specimens be increased, the average strength will be less, since failure will occur in the weakest section. To illustrate the theory, let us consider the strengths of links, and of chains formed of groups of these links, in a postulated statistical universe.[3] Assume that the links are of a certain grade and size, and the material and methods of manufacture are as constant as conditions warrant. The statistical relation between the mean strengths of the links and of chains of various numbers of links and between the standard deviation in the strengths of links and of chains will be demonstrated.

The mean tensile strength of the individual links in the universe from which we are selecting specimens for test will be designated as M_1, and the standard deviation of the strengths of the individual links in this universe will be designated as σ_1.

If we select at random a large number of chains of n links each from the universe, the mean strength M_n of such chains obviously will not be equal to M_1, because the weakest link in each of the group of n links in each chain will fail. The standard deviation of the strengths of the chains will also differ from that of the strengths of the individual links. If the number of chains considered is sufficiently large, we will have a statistical universe of chains, and the strength characteristics of these chains can be determined from the strength characteristics of the universe of links.

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[3] By the term "universe" the statistician implies the hypothetical background composed of an infinite number of individuals which is defined by the frequency curve delineating the relative frequency of occurrence of each possible value of the variable. In this case the variable is the tensile strength of the individual link.

The problem of finding the mean strength and the standard deviation of the strengths of the weakest links in groups of n, in terms of the mean and standard deviation of individual links has been solved by Tippett (4). A synopsis of these values is given in Table I. Thus, in this universe of individual links, the mean strength is designated as M_1 and the standard deviation of the strengths as σ_1. For the universe of chains of n links, the mean strength and the standard deviation of the strengths may be found opposite the value of n in the table.

TABLE I.—VALUES OF THE MEAN AND OF THE STANDARD DEVIATION OF THE STRENGTHS OF CHAINS OF n LINKS.[a]

Although Tippett (4) presents these values to six figures for the means and four figures for the standard deviations, these have been reduced to two places beyond the decimal in this table, as a greater number is not significant in most experimental work.

Number of Links, n	Mean Strength of Chains	Standard Deviation of Strengths of Chains
1	M_1	σ_1
2	$M_1 - 0.56\sigma_1$	$0.83\sigma_1$
5	$M_1 - 1.16\sigma_1$	$0.67\sigma_1$
10	$M_1 - 1.54\sigma_1$	$0.59\sigma_1$
20	$M_1 - 1.87\sigma_1$	$0.53\sigma_1$
60	$M_1 - 2.32\sigma_1$	$0.46\sigma_1$
100	$M_1 - 2.51\sigma_1$	$0.43\sigma_1$
200	$M_1 - 2.75\sigma_1$	$0.40\sigma_1$
500	$M_1 - 3.04\sigma_1$	$0.37\sigma_1$
1 000	$M_1 - 3.24\sigma_1$	$0.35\sigma_1$
100 000	$M_1 - 4.38\sigma_1$	$0.27\sigma_1$

[a] M_1 is the mean strength of individual links, and σ_1 is the standard deviation of the strengths of individual links in the parent group of links from which the chains are made.

As a concrete sample, compare the testing of a group of N chains of 10 links each, with the testing of a group of the same number ($10N$) of individual links. In the universe composed of the mean strengths of groups of $10N$ individual links, the mean strength will still be M_1, but the standard deviation of the mean strengths of such groups will be $\frac{\sigma_1}{\sqrt{10N}} = 0.316 \frac{\sigma_1}{\sqrt{N}}$, with a standard error $\sigma(\sigma_N)$[4] of $0.316 \frac{\sigma_1}{N\sqrt{2}}$. In the universe composed of the strengths of chains of 10 links, we find from Table I ($n = 10$) that the mean strength will be $M_1 - 1.54\sigma_1$ and the standard deviation of the strengths of the chains will be $0.59\sigma_1$. The mean strength of groups of x such chains will also be $M_1 - 1.54\sigma_1$ but with the standard deviation of $0.59 \frac{\sigma_1}{\sqrt{x}}$ and a standard error of $0.59 \frac{\sigma_1}{x\sqrt{2}}$.

If we are to test 10-link chains, and obtain their mean strength with the same precision as that in obtaining the mean strength of $10N$ individual links, the standard deviation of both means must be equal. Designating the number of 10-link chains to be tested as x, then

$$0.316 \frac{\sigma_1}{\sqrt{N}} = 0.59 \frac{\sigma_1}{\sqrt{x}}$$

Solving, we find $x = 3.5N$

Under these conditions, 3.5 times as

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[4] The term standard error is used here to denote the standard deviation of the standard deviation, and is a measure of the variability or scatter in a number of observed values of the standard deviation. The standard deviations and standard errors are given in this paper primarily to indicate the relative scatter of the values to which they are assigned and thus indicate the reliance that we may attribute to those values. If M_1 is the mean strength of individuals, and σ_1 the standard deviation in the strength of individuals, then the standard deviation of the average strength of n individuals σ_n is $\frac{\sigma_1}{\sqrt{n}}$ and the standard error of this latter, $\sigma(\sigma_n) = \frac{\sigma_1}{n\sqrt{2}}$. It should be noted that the standard deviations in the universes under consideration are not known, and in this paper σ_1 is a purely hypothetical value. We can compute $S_1 = \sqrt{\frac{\Sigma V^2}{n}}$ or the root mean square error; the best estimate of σ_1 is then $\frac{S_1 n}{n-1}$, or $\sigma_1 = \sqrt{\frac{\Sigma V^2}{n-1}}$ (5, 6, 7).

many links are tested. If it is assumed that all links in a chain are of no value after test, the testing of chains destroyed 3.5 times as many links. However, in the testing of individual links $\frac{10}{3.5} =$ 2.85 times as many tests were made.

The methods used in computing the strengths and the strength dispersion of chains of different numbers of links may be applied by use of Table I for tension test specimens in which the cross-section remains constant and the length changes. Such specimens include ropes, chains, cables, metal rods, such as reinforcing bars, in all of which the stress may be assumed to be uniform across every lateral section, and constant throughout the length of the specimen.

In computing the average strength and the standard deviation of the strengths of longer specimens from data for shorter ones, the length of the shorter specimen, within which failure may occur, is to be taken as the unit length, and the length within the longer specimen in which failure may occur, divided by the unit length, is to be taken as n. It is to be noted that these values of n need not be integers, and that any value, including fractional values, may be obtained by plotting the values in Table I and reading the required value for n from the graph.

Compression:

Compression test specimens of medium length fail essentially by shearing in a plane inclined to the base of the specimen at an angle α_0 peculiar to the material. The angle α_0 has been termed the angle of shear. If the specimen is shortened so that the length is less than the product of the diameter (or width) and the tangent of α_0, then the strength of the specimen is increased. The present analysis is limited to specimens of greater than this length; a more comprehensive analysis of the compression specimen is given in another paper (8).

The strength characteristics of a compression specimen can be computed from that of a shorter specimen, as follows: From the length of the short specimen the length d tan α_0 is subtracted, where d is the diameter (or the width of a square specimen). The remaining length is the length of "free failure," that is, the length in which failure may occur. This length is the "unit length." We then in the same way find the length of "free failure" of the longer specimen, and designate the ratio of this length to the unit length as n. From the mean strength and the standard deviation of the strengths of the short specimens (M_1 and σ_1 in Table I) we can find the mean strength and the standard deviation of the strengths of the longer specimens.

Torsion:

In a torsion specimen of medium length the failure in brittle materials occurs in the form of a helicoidal or conchoidal surface. The projection of this surface on the axis of the torsion specimen will have a length which we will designate as S. Our theory, as in the case of the compression specimen, will not apply when the length of the specimen in which failure will occur is less than the value S. Thick metal tubes fail in a plane perpendicular t theo axis, in which case $S = 0$.

In determining the mean strength characteristics of longer specimens from the mean strength and standard deviation of the strengths of shorter ones, the procedure is as follows: subtract the length S from the length of each specimen in which failure will occur. The ratio of the net length of the longer to that of the shorter specimen is n. Apply the values in Table I as before.

Flexure:

The strength characteristics of beams of different dimensions have been analyzed previously by the author (2). Only a summary of the findings will be given here.

The modulus of rupture of beams of the same cross-section and of any one type of loading, such as central, or third-point, may be compared by means of Table I. The length of the shorter beam between supports is taken as the unit length, the ratio of the length of the longer to the shorter beam is n, and is to be applied in Table I to find the mean modulus of rupture and the standard deviation of the moduli of rupture of the longer beams. The weakest-link theory also applies to the change in these parameters caused by increase in beam depth, where beam span and width, and method of loading remain constant. The shallow beam depth corresponds to the unit depth, a beam n times greater in depth will have the characteristics associated with n in Table I.

EFFECT OF CHANGE IN AREA OF CROSS-SECTION (SUMMATION-STRENGTH THEORY)

Compression:

In the testing of geometrically similar concrete cylinders, (that is, specimens having a constant ratio of length to diameter) it was found (1) that the compressive strength (ultimate stress) of the cylinders was approximately the same regardless of the diameter. However, the standard deviation of the compressive strengths decreased with increase in cylinder diameter. This change was in accord with computations based on the theory of probability.

Thus, if σ_1 is the standard deviation of the compressive strengths of cylinders of unit area, and σ_a the standard deviation of the compressive strengths of cylinders a units in cross-section,

$$\sigma_1 = \sigma_1/\sqrt{a} \ldots\ldots\ldots (1)$$

As the square roots of the areas are proportional to the diameters, the standard deviation of the compressive strength of cylinders is inversely proportional to the diameters.

Let us now see the relative information gained by testing cylinders of two diameters. First assume that we are making tests of cylinders 6 in. in diameter by 12 in. long. The mean compressive strength of the individual cylinders in the universe from which we are selecting specimens for test will be M_1, and the standard deviation of the compressive strengths of the individual cylinders in this universe is σ_1. Then for a universe of groups of n cylinders each, the mean strength will also be M_1, but the standard deviation for the means of the groups will be $\sigma_1/\sqrt{n}$ with a standard error of $\sigma_1/n\sqrt{2}$.

Now let us test larger cylinders dimensioned $6y$ in. in diameter by $12y$ in. long and of the same material as the 6 by 12-in. cylinders. The mean compressive strength of the individual cylinders in this universe from which we are selecting specimens will again be M_1 but the standard deviation of the compressive strengths of individual cylinders will now be σ_1/y, y being the ratio of the diameter of the larger to the smaller cylinder. If we test groups of n such cylinders, the groups will be from a universe in which the standard deviation of the mean compressive strengths will be $\sigma_1/y\sqrt{n}$ with a standard error of $\sigma_1/yn\sqrt{2}$. Thus an increase in the precision is obtained by testing larger specimens.

However, if for the larger cylinders we test groups in the number of nx cylinders which will give the same standard deviation for the mean as for the groups of n 6-in. cylinders, we find $\frac{\sigma_1}{\sqrt{n}} = \frac{\sigma_1}{y\sqrt{nx}}$, and therefore $x = 1/y^2$. That is, we need only test the number of cylinders which is equal to the reciprocal of the square of the ratio of the diameters.

Thus, we need only test one fourth the number of cylinders if the larger cylinders are 12 in. in diameter. But the weight of the 12-in. cylinder is eight times that of the weight of the 6-in. cylinder, and therefore we would have to test twice the total weight of material. We also call attention to the 240 lb. that is the approximate weight of the 12-in. cylinder.

From the foregoing it follows that when the summations of the cross-sectional areas of the cylinders of the two sizes are equal, equal information is gained. That is, $4n$ of the 6-in. cylinders will have an area equal to n of the 12-in. cylinders. Thus, if we reduce the diameter of the test specimen, we need only make the number proportional to the ratio of the areas to obtain equal statistical information.

Tension:

The strength characteristics of tension specimens of differing cross-sectional areas may be assumed to be the same as those governing the compression specimens. There is no restriction as in the compression specimens that the l/d ratio should be constant for the tension specimens. For the comparison of tension specimens of varied cross-sections, the length of the specimens should be the same.

Flexure:

In a previous paper (2) it was demonstrated that in varying only the width of the beam, the summation theory applied. That is, the modulus of rupture remains constant with increase in width, but the standard deviation of the modulus of rupture of a beam of width w is $\sigma_w = \sigma_1/\sqrt{w}$ where σ_1 is the standard deviation of moduli of rupture of beams of unit width.

THE USE OF SMALL SPECIMENS

In some instances it is impossible to secure other than small specimens of a material for test. One example of this is the spun concrete pipe. In the spinning process water and cement are extracted, and the concrete after placing is radically different from the original mix. The original mix is placed rather wet, whereas the formed concrete in the pipe is very dry. Gain in strength results from the reduction in water content, partially compensated for by the loss in cement. The concrete is so dry and compacted in the spinning process that, by very careful handling, it may be removed from the form as soon as spun.

The test cylinders of the standard size made from the original mix obviously would not have properties at all like the concrete in the pipe. The presence of wire reinforcement or steel casing prevents testing the concrete for strength by axial compression of a section of the pipe.

Ross (9) cut small specimens from spun pipes with walls 1.85 in. thick. The aggregate was of the $\frac{3}{4}$-in. size. The specimens were 2.1 by 1.8 by 3.7 in., and had an average compression strength of 7600 psi. at the age of approximately 2 months. The 6 by 12-in. cylinders made from the original mix had strengths at 28 days of 5000 psi. Both the pipes and cylinders were cured three days in steam under canvas, at atmospheric pressure, then stored in air. Under this condition of storage, little strength increase is to be expected in the period from 28 days to two months. The small specimens apparently were not weakened by the comparatively large size of the aggregate (approximately $\frac{3}{4}$ in.). The coefficient of variation[5] of the compressive strengths of the small specimens was approximately 11 per cent. This may appear to be large. By application of Eq. 1, however, the coefficient of variation of 6 by 12-in. cylinders of the material would be 3.6 per cent which is low for concrete cylinders of this size.

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[5] For convenience in the following discussion, strength dispersion has been expressed in terms of the coefficient of variation, which is the standard deviation expressed as a percentage of the mean strength.

Another example may be cited in the testing of small specimens of cast stone. In an investigation of the properties of cast stone (10) many of the 68 samples tested were so limited in size that only small specimens could be cut from them. In order to give additional information on the samples, after testing the 1 by 1 by 8-in. flexural specimens three sections each 2 in. long were cut from the bars after test. None of the 1 by 1 by 2-in. prisms gave unusually low strengths. The average of the coefficient of variation of these specimens was 13 per cent, compared to the coefficient of variation of 6 per cent for the 2-in. diameter, 2-in. high cores from the same samples. The coefficient of variation of 13 per cent for the 1-in. square specimens would be equivalent to $13/\sqrt{28.3} = 2.4$ per cent for 6-in. diameter cylinders of the same material. This may appear to be small; but when we consider that with two exceptions the average of the largest aggregates was less than approximately 0.3 in. in size, then, as the coefficient of variation of the strengths is proportional to the size of the aggregate (1), 1-in. aggregate in 6-in. diameter cylinders would develop a standard deviation of $2.4 \times \frac{1.00}{0.30} = 8.0$ per cent, a value not discordant with the usual results of tests of concrete cylinders.

It may be mentioned that in two samples of these cast stones the aggregate was of the ½-in. size, just one half of the width of the cross-section. The tests of specimens from these two samples showed no departure from normality, either in their method of breaking or in any lowering in strength. To substantiate the reliability of tests of these two samples the following data are given. The mean strengths of the prisms were 12,600 and 15,780 psi., respectively. The average ratio of strengths for the two is 0.753. The average of the ratios of prism to cylinder strengths for all other specimens was 0.812. In the opinion of the author a number of the tests were clearly erratic in that the strengths of the prisms, with larger *l/d* ratio, were less than the strengths of the 2 by 2-in. cylinders. If we exclude the ratios for this group, the ratios of prism to cylinder strengths of the remaining 58 samples is 0.762. The value obtained on specimens with much smaller size aggregate (with two exceptions, ¼-in. size and smaller) is practically the same as that obtained with the ½-in. aggregate, thus demonstrating that aggregate as large as half the width of the specimen does not reduce the strength of that specimen.

SUMMARY

Changes in the dimensions of specimens that affect the strength and the scatter in strength are of two types. The weakest-link theory appears to be the unique and satisfactory statistical theory of strength which can be applied to variations of the first type.

This theory is applicable to increase in the length of specimens subjected to tension, to compression, to torsion, and to flexure. It is also applicable to increase in the depth of flexural specimens. Tippett's tables (4) give the reductions in the mean strength, caused by changes of the first type.

Variation in the area of the cross-section is of the second type. Unlike variations of the first type, there is no obvious statistical theory of strength which may be applied to the second type of dimensional change. The changes in strength and strength dispersion will depend upon the mechanism of failure of the material, a phenomenon about which little is known. The strength-summation theory appears to apply for several materials. According to this concept, the strength of the material is independent of the area of the specimen upon which tests are made, provided that the length of the specimens remains unchanged in tension tests, and that the l/d ratio is constant in compression tests. The standard deviation of the strengths of the specimens varies according to the equation:

$$\sigma_a = \sigma_1/\sqrt{a}$$

where σ_a is the standard deviation of the strengths of specimens of cross-section area a, and σ_1 is the standard deviation of the strengths of specimens of unit area. The equation applies to increase in the area of tension and compression test specimens and increase in the width of beams.

The use of relatively small specimens, much smaller than those commonly used in tests of materials such as concrete, is demonstrated to be sound.

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(9) Culbertson W. Ross, "Tests of Prestressed Concrete Pipes Containing a Steel Cylinder," *Proceedings*, Am. Concrete Inst., Vol. 42, p. 37 (1946).

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DISCUSSION

Mr. R. L. Templin[1] *(by letter)*.—In commenting on this excellent paper it would seem worth while to emphasize a dependence of the results obtained by the analytical methods upon the assumption of uniform stress distribution both throughout the lateral section and length of the test specimens. Unfortunately, in many tests of materials this condition is not realized and consequently differences reasonably might be expected between computed and measured data.

Presumably there is some minimum l/d ratio for each material, below which the strength of the material would be affected appreciably. This is in accordance with results found by W. E. Dalby.[2] Furthermore, although the author has concerned himself primarily with strength data, yet for tension tests of ductile materials wherein elongation values might be of interest, there would be appreciable effects on the elongation values in this same range of specimen size since the nature of the fracture would be influenced considerably by the geometry of the specimen.

A conception of ultimate compressive strength is generally meaningless when dealing with ductile materials because failure either occurs by buckling or involves excessive and generally nonuniform lateral deformations.

Finally, while the author's experimental evidence seems to indicate the satisfactory use of an appreciably wider range of sizes of specimens than customary, yet more experimental data would seem desirable before attempting to define size range limits for materials not considered by the author.

Mr. John Tucker, Jr. *(author's closure by letter.)*—Mr. Templin's constructive comments are appreciated. The applicability of the statistical theory to the compressive strength of ductile materials is questioned by him. Short steel columns, which may be considered in this category, have been shown[3] to approximate the strength reduction with length forecast by statistical theory.

The theorems in the paper have been offered to show the possible advantages of change in size of specimen. If the test results do not coincide with predicted strength changes, there is an indication that the stress conditions in the specimen have been changed because of changes in size and this may aid in eliminating faulty test procedure.

We heartily concur with Mr. Templin's desire to secure more data before changing or defining size-range limits.

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[1] Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.

[2] W. E. Dalby, "Strength and Structure of Steel and Other Metals," Longmans, Green and Co., New York, N. Y., pp. 68 and 69 (1923).

[3] J. Tucker, Jr., "The Compressive Strength Dispersion of Materials, with Applications," *Journal*, Franklin Inst., Vol. 204, December 1927, p. 751.

THE MAXIMUM STRESSES PRESENT AT FAILURE OF BRITTLE MATERIALS[1]*

BY JOHN TUCKER, JR.[2]

SYNOPSIS

It is shown by a statistical theory of strength how stresses with magnitudes much beyond those usually considered as the strength of the material may be present in a portion of a test specimen. It is theoretically demonstrated that the modulus of rupture as usually calculated should be much greater than the tensile strength. Analysis demonstrates that the load at failure of a cement briquet does not have a fixed ratio to the tensile strength of the material. It is also shown that in a concrete cylinder tested in compression, with ends restrained against lateral expansion, the tensile stresses present in a small portion of the volume are too small to cause a tensile failure.

According to the usually accepted classical maximum stress theory for the strength of materials, a specimen will fail when the stress at any point, or over any area or volume, no matter how small, reaches a definite value known as the strength of the material. By this theory, a "characteristic" strength, such as the modulus of rupture, is independent of the size of the specimen.

In the past decade the application of the theory of probability has provided a means for estimating the effects of size and shape of specimen on the characteristic strength (**1**, **2**, **3**).[3] It has been demonstrated (**2**) that the strength and the standard deviation of the strength are independent of the dimensions of the test specimen only in the purely hypothetical case where there is no variation in the strength of the material throughout the specimen. In all actual materials the strength varies throughout, and therefore the characteristic strength depends upon the size and shape of the specimen.

It is the purpose of this paper to demonstrate, by a statistical strength theory based on the laws of probability, that for specimens in which the stresses are not uniformly distributed, the maximum stresses may be much higher than the strength of the material as determined by tests of specimens in which the stress is uniformly distributed. Local stresses much above the ordinarily accepted strength of the material may therefore be present at failure of the specimen.

MODULUS OF RUPTURE

In a previous paper (**3**) the author postulated certain statistical theories, concerned with the strength of materials, and computed by these theories the relative values of the modulus of rupture and of its standard deviation for beams varying in dimensions and in methods of loading, and showed how test data to a large degree substantiated these findings. In that analysis the strength characteristics of a beam of one dimension were predicted from elementary sections of a beam of different dimensions.

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* Manuscript received too late for general distribution before publication in *Proceedings*. Any additional discussion that is received for this paper will be published in the 1946 *Proceedings*.

[1] A brittle material is here defined as one which has a negligibly small flow under stress during the period of testing.

[2] Chief, Cement and Concreting Materials Section, National Bureau of Standards, Washington 25, D. C.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 973.

In the present analysis we start with the strength characteristics (mean strength and standard deviation of the strength) of specimens of the material in uniform tension, and compute the strength characteristics of fibers from those specimens, based on theory which included statistical concepts. We then predict the strength of a beam or of a briquet assuming that the beam or the briquet is composed of a number of these fibers. Because of the presence of aggregate which is not small in size relative to half the beam depth, the stress distribution assumed in the usual analysis would not be expected, and it is anticipated that our computations would be only approximations.

It is not apparent which particular statistical theory, as for example those postulated in reference (**3**) will apply to different materials, and which should be used to predict the changes in strength and in scatter in strength, concomitant with change in dimensions. In our present analysis, the tensile strength characteristics of elementary fibers, of which a tension test cylinder is assumed to be composed, must be determined from the strength characteristics of the cylinder. Test data, for example on concrete (**1**) and plastics (**4**) indicated that for a change in cross-sectional area, the summation theory applied. If we apply this theory to our analysis in the present paper, the predicted modulus of rupture is but little more than the tensile strength of the material, a result discordant with fact. If we apply the weakest link theory (**3**) we obtain a predicted modulus of rupture greater than the tensile strength, but not so great as experiment shows. A combination theory is offered, which has the merit of predicting values for the modulus of rupture which are adequately large.

BASIC TEST DATA FOR COMPUTATION OF THEORETICAL MODULUS OF RUPTURE

The modulus of rupture was computed by statistical theory, on the basis of three assumed stress-strain relations for the concrete. One assumption was that the material obeyed Hooke's law. Another was that the stress-strain relation of the concrete was that obtained by Schuman and Tucker (**5**) on 4-in. diameter cylinders in which failure occurred in an 8-in. length.

The Standard Method of Test for Flexural Strength of Concrete (C 78 - 44),[4] (Using Simple Beam with Third-Point Loading), requires an increase in extreme fiber stress of 150 psi. per minute, with more rapid loading up to one half the modulus of rupture, a total loading time of not more than 4 min. for concretes with the characteristics we are considering. The determination of the stress-strain relation as determined by Schuman and Tucker required at least three to four times as long, and there was considerable flow in the concrete. Consequently, a curve intermediate between that given by Hooke's law and that representing data of Schuman and Tucker has also been selected as another basis for computing the theoretical modulus of rupture by statistical theory.

For the first stress-strain relationship it was assumed that Hooke's law was valid till failure

$$s = E_c e \quad \ldots\ldots\ldots\ldots (1)$$

where

s = stress in pounds per square inch,
e = strain, and
E_c = modulus of elasticity, 4,000,000 psi.

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[4] 1944 Book of A.S.T.M. Standards, Part II, p. 480.

The tensile strength was assumed to be 400 psi., the ultimate strain, e_0 being therefore 0.00010.

The second stress-strain relationship was assumed to be

$$s = E_c e_0 (x - 0.06x^2 - 0.04x^3) \quad (2)$$

where $x = e/e_0$, the value of E_c is 4,000,000 psi., the tensile strength is 400 psi., and the ultimate strain $e_0 = 0.00011$.

The third stress-strain relationship was:

$$s = E_c e_0 (x - 0.12x^2 - 0.08x^3) \quad (3)$$

where all quantities except e_0 are the same as for Eq. 2. e_0 in this case is 0.000125. The characteristics are representative of the data of Schuman and Tucker.

The tensile strength for all three equations had a standard deviation of $\sigma_c =$ 24 psi (6 per cent).

In the analyses, by both the weakest link and the combination theories, discussed in the next section, the 4-in. diameter cyclinder is assumed to be composed of n fibers of equal areas and having lengths of 8 in., the length of the cylinder. The number of fibers chosen for such an analysis should be such that the variation in stress in the fiber, and consequently the variation in the probability of failure in this stress range is small. These conditions are met by making $n = 100$. If a much larger value for n is chosen, the numerical results would differ somewhat from those obtained when $n = 100$, but it is believed that the results would not be significantly different. The analysis in each case would show a modulus of rupture greater than the tensile strength.

Weakest Link Theory:

In the weakest link theory (**7**), let us designate the mean strengths of the fibers as M_1 and the standard deviations of their strength to be σ_1. If there are n fibers in the test cylinder, then the strength characteristics are given in Tippett's tables (**6**, **7**). For example, if $n = 100$, we look for this value of n in the table and find the strength of the cylinder (M_c) to be $M_1 - 2.51\sigma_1$, and the standard deviation of the strength of the cylinder (σ_c) will be $0.43\sigma_1$. In the data selected as basis for our computation the mean strength of the cylinder was 400 psi., with a standard deviation of $\sigma_c = 24$ psi. (6 per cent). Thus $0.43\sigma_1 = 24$ psi. (coefficient of variation, $v = 6$ per cent) and the standard deviation of the strength of the fiber is $\frac{24}{0.43} =$ 56 psi. ($v = 14$ per cent). Therefore the mean strength of the cylinder is $M_1 - 2.51\sigma_1 = 400$ psi., and the mean fiber strength is $M_1 = 400 + 2.51\sigma_1 = 540$ psi.

To simplify the computation of the theoretical modulus of rupture the size of beam was selected such that the length of the beam between third-point loads was equal to the 8-in. length of the fibers in the tension specimen, and one half the area of the beam was made equal to that of the area of n (= 100) fibers, the same as the area of the 4-in. diameter tension test cylinder. The problem is then to compute the modulus of rupture for a beam 4 in. wide, 6 in. deep, tested at third points, on a 24-in. span. We will assume the fiber to be rectangular in cross-section, equal in width to the width of the beam, and of thickness equal to one one-hundredth of half the beam depth.

The fibers in the beam will be assumed to possess the strength characteristics of the fibers of the tension test cylinder, that is, to have the same mean strength and the same standard deviation in strength.

The probability of the beam resisting failure is then the product of the probabilities of each of the fibers resisting failure under the stress to which they are subjected. From the probabilities of failure of the beam at a number of loadings, the mean value of the modulus of rupture and the standard deviation of the modulus of rupture may be calculated (3). Computations were made assuming that Hooke's law holds and also according to stress-strain relations of Eqs. 2 and 3.

Combination Theory:

In this method, all computations are the same as for the weakest link theory with the exception of the computation of the strength characteristics of the fibers. In this hypothesis, if the standard deviation of the strengths of fibers is σ_1 then the standard deviation of the strength of the 4-in. diameter test cylinder is assumed to be $\sigma_c = \sigma_1/\sqrt{n}$ where n is the number of fibers in the cylinder. The mean strengths of fiber and cylinder are assumed to bear the same relationship as in the weakest link theory and in Tippett's tables. Therefore the mean strength of the fiber being M_1, the mean strength of the cylinder (with 100 fibers) will be $M_1 - 2.51\sigma_1$. Thus, from our basic data $\sigma_c = 24$ psi. (6 per cent) and hence $\sigma_1 = \sigma_c\sqrt{100} = 240$ psi. $= 60$ per cent of M_c and $M_1 - 2.51\sigma_1 = M_1 - 602.4 = 400$ psi., therefore $M_1 = 1002.4$ psi. or 250.5 per cent of M_c.

From this point, the modulus of rupture of the beam is calculated in the same manner as outlined under the previous section on the weakest link theory. That is, the probability of the beam resisting failure is the product of the probabilities of all the fibers, under their individual stresses, of resisting failure.

Experimental Confirmation of Theory:

Although it has long been recognized that the modulus of rupture is considerably larger than the tensile strength of concretes, the ratio of these values is not definitely known, particularly because of the great difficulty in the measurement of the tensile strength. Slight eccentricity in loading, which causes large errors, and nonuniform gripping of the specimens will give values below the true tensile strength of the material. Gonnerman and Schuman (8) give ratios of modulus of rupture to tensile strength which vary from 1.42 to 5.00, the latter value being exceptional and for very weak specimens. For a concrete with a compressive strength of 4500 psi., which, according to Schuman and Tucker (5) would correspond to a tensile strength of 400 psi., Gonnerman and Schuman give a ratio of 1.65 between the modulus of rupture and the tensile strength. But as Kellerman showed in his discussion of the paper by Gonnerman and Schuman, many of the specimens broke at the end of or within the grips, thus indicating that the specimen broke at a stress less than the true tensile strength of the material.

The modulus of rupture of concrete is therefore probably not as large, compared to the tensile strength, as has been assumed. The author believes that the modulus of rupture is approximately 45 to 65 per cent greater than the tensile strength, or from 580 to 660 psi. for a concrete with a tensile strength of 400 psi.

The ultimate strain of the extreme fiber of concrete beams under load is not known with certainty. Hatt (9) gives measured strains of from 0.00013 to 0.00019 for loads less than those causing failure. These values exceed that of 0.000125 mentioned previously in this paper. This indicates that the ultimate strain of the concrete in the extreme fiber of a beam is appreciably larger than the ultimate strain of like concrete tested in pure tension. The increase in strain over the ultimate strain in pure tension is probably of the order of 50 per cent.

Theoretical Modulus of Rupture:

According to the classic maximum stress theory, the beam will fail when the stress in the extreme fiber reaches the value of tensile strength of the material. For the value of 400 psi. which we have assumed as the tensile strength of our concrete, if that concrete obeys Hooke's law, then the modulus of rupture would likewise be 400 psi.

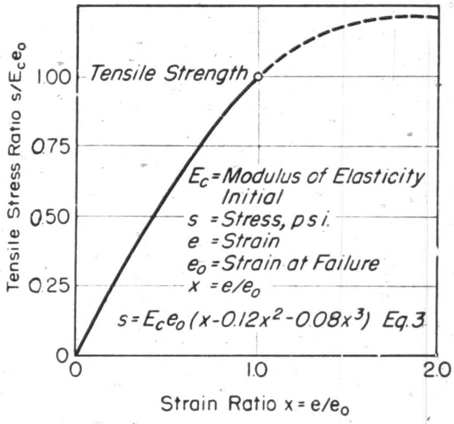

FIG. 1.—Stress-Strain Relation of Concrete in Tension.

If the material has the stress-strain characteristics of Eq. 2, and it is assumed that plane sections remain plane, then the modulus of rupture will be 422 psi.

If, however, the concrete has the stress-strain relationship as given by Eq. 3 (Fig. 1), failure will occur when the stress in the extreme fiber is 400 psi., but now the stress distribution in the beam is as given in Fig. 2, the ultimate strain being 0.000125. The modulus of rupture of such a beam would be 450 psi.

Thus classic theory predicts but a small part of the increase in modulus of rupture over the tensile stress, and of the ultimate strain of the extreme fiber over the ultimate strain of the concrete tested in pure tension.

Modulus of Rupture by Statistical Theory of Strength:

Weakest Link Theory.—According to the classic theory of strength and for concrete obeying Hooke's law, both the tensile strength and the modulus of rupture are 400 psi. The probability of failure by the weakest link theory, under this stress condition is computed by the method outlined above to be the negligible quantity of 0.027. This illustrates the reason for the statistical theory predicting a much higher value for the modulus than does the classic theory.

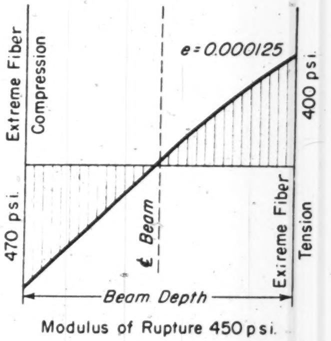

FIG. 2.—Stress Distribution at Rupture According to Classic Maximum Stress Theory. (Stress-strain relation of Eq. 3.)

For a concrete with the stress-strain relation of Eq. 1, the mean value for the modulus of rupture by the weakest link theory is 470 psi., with a standard deviation of 34 psi. (7.2 per cent). The extension of the extreme fiber at failure is 0.00012, and 15 per cent of the tension side of the beam is stressed beyond the tensile strength of specimens tested in pure tension.

The modulus of rupture, computed by weakest link theory, for the stress-strain assumptions of Eq. 2 is 500 psi., with a standard deviation of 36 psi., (7.2 per cent). Eighteen per cent of the fibers in the tension side of the beam are stressed beyond the ultimate strain.

The extreme fiber at failure is stressed to 465 psi., with a strain of 0.00013.

Let us now consider a beam composed of concrete with stress-strain characteristics of Eq. 3. If such a beam is subjected to a bending which will develop a stress of 400 psi. in the extreme fiber, the stress-distribution is as shown in Fig. 2. As computed by weakest link theory the probability of failure under this load is only 0.05. Again we see that statistical theory predicts a larger modulus of rupture than does the classic theory.

The modulus of rupture as computed by the weakest link theory for the stress-strain assumption of Eq. 3 is 550 psi. with standard deviation of 41 psi. (7.5 per cent). The extreme fiber, at failure, is stressed to 455 psi., with a strain of 0.000165. Note that 22 per cent of the area of the tension side of the beam has been stressed beyond the tensile strength and the ultimate strain of the material, as tested in pure tension.

Up to this point, our analysis has been based on a 4-in. diameter tension test specimen with a strength of 400 psi., and a standard deviation of 24 psi. (6 per cent). For a standard deviation of 10 per cent, the modulus of rupture computed by the weakest link theory, and based on the stress-strain relation of Eq. 3 is 585 psi., with standard deviation of approximately 88 psi. (15 per cent). For this condition, the stress in the extreme fiber is 470 psi. and the strain is 0.00018.

Combination Statistical Theory of Strength.—By the combination theory, for a material obeying Hooke's law, having a tensile strength of 400 psi., with $\sigma_c = 6$ per cent, the modulus of rupture is computed to be 590 psi. with a standard deviation of 118 psi. (20 per cent). The ultimate strain is 0.00015, and 32 per cent of the tension half of the beam is stressed beyond the ultimate stress and strain of the material tested in pure tension.

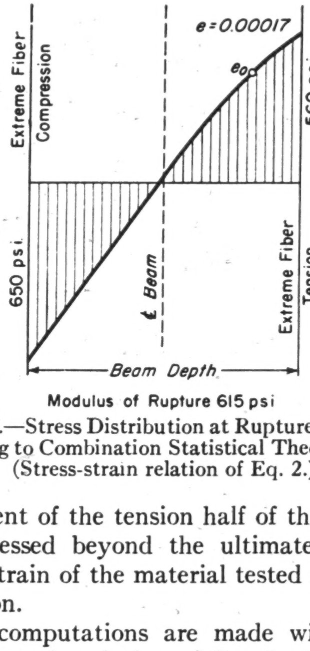

FIG. 3.—Stress Distribution at Rupture According to Combination Statistical Theory. (Stress-strain relation of Eq. 2.)

If computations are made with the stress-strain relation of Eq. 2, then the

TABLE I.—BEAM CHARACTERISTICS CALCULATED BY SEVERAL THEORIES.

Theory of Failure	Modulus of Rupture[a], psi.			Extreme Fiber Stress and Strain at Failure of Beam						Area of Tension Half of Beam Stressed Beyond Tensile Strength, per cent		
				Stress, psi.			Strain, in. per in. × 10^5					
	Eq. 1 (Hooke's Law)	Eq. 2	Eq. 3	Eq. 1	Eq. 2	Eq. 3	Eq. 1	Eq. 2	Eq. 3	Eq. 1	Eq. 2	Eq. 3
Classic	400	422	450	400	400	400	10	11	12.5	0	0	0
Weakest link	470 (±7.2%)	500 (±7.2%)	550 (±7.5%)	470	465	455	11.7	13	16.5	15	18	22
Combination	590 (±20%)	615 (±11.5%)	760 (±5.4%)	590	560	465	15	17	23	32	36	50
Combination (σ_c = 10 per cent)			585 (±15%)			470			18			28

[a] The coefficients of variation are given after the modulus of rupture.

modulus of rupture is found to be 615 psi. with a standard deviation of 71 psi. (11.5 per cent). The stress in the extreme fiber at failure of the beam is 560 psi., and its strain is 0.00017, and 36 per cent of the tension half of the beam is subjected to stresses and strains beyond the ultimate in specimens tested in pure tension. Figure 3 shows the stress distribution of the beam at failure.

If computations are made with the stress-strain relations of Eq. 3 (Fig. 1) the modulus of rupture is found to be 760 psi., with the ultimate strain 0.00023 and approximately 50 per cent of the tension half of the beam is stressed beyond the ultimate stress and strain of the material tested in pure tension.

A summary of the computations is given in Table I.

Discussion—Comparison of Theoretical and Observed Modulus of Rupture:

It is very likely that the concrete upon which our computations are based will have stress-strain relations intermediate to those given by Eqs. 2 and 3. In the following, the values computed on the basis of the two equations will be cited as limits.

By the classic maximum stress theory of strength, in which it is assumed that the beam will fail when the extreme fiber is stressed to the tensile strength of the material, the modulus of rupture will lie between 422 and 450 psi. The ratio of the modulus of rupture to the tensile strength (1.05 to 1.12) is much below the value of from 1.45 to 1.65 that is obtained experimentally and the classic theory predicts no increase in the strain in the extreme fiber at failure beyond the ultimate strain in pure tension.

By the weakest link theory, the modulus of rupture will lie between 500 and 550 psi. The ratio of the modulus to the tensile strength in this case is 1.25 to 1.37, respectively, a distinct improvement on the values obtained by the classic theory, but again lower than test values. The strain in the extreme fiber at beam failure is increased to the range 0 00013 to 0.000165, which is considerably larger than the ultimate strain in pure tension, but a lesser value than those observed in tests. At failure of the beam, from 18 to 22 per cent of the tension area of the beam is stressed beyond the tensile strength of the material.

By the combination theory we find the modulus of rupture would lie between 615 and 760 psi. The ratios of these values to the tensile strength are 1.54 and 1.90, respectively. The strain of the ultimate fiber at beam failure would lie between 0.00017 and 0.00023 in. per inch. We see that by this hypothesis, the ranges in the values of the modulus of rupture and of the ultimate extreme fiber strain overlap the range of values obtained from test data. At failure of the beam, 36 to 50 per cent of the tensile half of the beam is stressed beyond the tensile strength of the material.

By either statistical theory, the modulus of rupture and the strain in the extreme fiber at failure of beam are considerably greater than the tensile strength and the ultimate tensile strain, respectively, of the material.

Although computations by the weakest link theory predict values of the modulus of rupture and ultimate strain of the extreme beam fiber considerably above the tensile stress and ultimate tensile strain, these values are below those obtained on beam tests. The theory predicts that an appreciable area of the beam will be stressed beyond the tensile strength of the material. On the other hand, the combination theory predicts a modulus of rupture approximately equal to the mean observed value for one assumed stress-strain relation, and much higher for another assumed stress-strain relation. The combination theory predicts an even greater percentage of the beam being stressed beyond the tensile strength of the material.

THE TENSION TEST BRIQUET

The tension test briquet has been selected for analysis because the internal stresses vary so widely throughout the specimen. The tension briquet is at present used as test specimen in five A.S.T.M. specifications for plasters.[5] The briquet has long been used as a strength test specimen in portland cement specifications. A few years ago the use of the cube was made optional, but in the war emergency the briquet was the mandatory test specimen. In spite of widespread condemnation for many years, steps have only now been taken to replace it by the compression cube. Because of the wide use of the briquet as a test specimen for portland cement and other materials, and the large amount of data thus obtained, an analysis of the briquet may be of service through preventing the misinterpretation of the data.

The strain distribution of the briquet under tension has been studied photoelastically by Coker and Filon (**10, 11**). The stress distribution of the American standard briquet at the transverse centerline, for material obeying Hookes' law, is approximately as shown in Fig. 4(*a*) in which s_y is the longitudinal stress and s_x the transverse stress. Although Coker and Filon do not present the stress distribution for the American briquet, Coker indicates (**10**) that the stress reaches a value 70 per cent greater than the mean longitudinal stress at midsection.

The strain distribution in the briquet is not the same for other sections parallel to the one at midlength, but in the waist region, for a length of about 0.4 in. along the longitudinal axis, in which almost all failures occur, the strain distribution does not depart materially from the distribution at midlength. In applying the statistical theory of strength, it was assumed that failure occurs in the 0.4-in. long middle portion of the briquet; that, in this length, the briquet is of constant width and thickness (1 by 1 in.); and that the stress distribution in any transverse section within this length is the same as at midlength.

Experimental data for the computation of the strength of the briquet upon statistical theory were obtained on some tension specimens of the type of those used by Schuman and Tucker (**5**). A group of briquets made of the same mortar was tested at the age of 7 days. It would have been desirable to use the 1:3 standard Ottawa sand mortar with the consistency that is used in the specification tests. However, that mortar is harsh and dry and the test method requires vigorous thumbing of the mortar in the fabrication of tension test briquets, a process not feasible for the cylinder. The plastic mortar used in the specification cube tests was therefore selected. The consistency of this mortar was such that the briquets and the cylinders could be fabricated in an identical manner by gentle puddling.

The test results were as follows:

	Number of Specimens	Mean Tensile Strength, psi.	Standard Deviation, psi.
4-in. diameter cylinders	4	312	2.2 (0.72 per cent)
Briquets	18	307	30.7 (10 per cent)

The number of test specimens may appear inadequate. However, the results were obtained through controlled experiment, the variations in strength being essentially due to the heterogeneity of the material. Therefore, the reliance which may be placed upon the results is given by the calculated statistical parameters. The mean strengths have standard deviations of $\frac{2.2}{\sqrt{4}} = 1.1$ psi. (0.35 per cent) and $\frac{30.7}{\sqrt{18}} = 7.5$ psi. (2.4 per cent) for the cylinder and the briquet, respectively. The most important constant for our statistical calculations is the standard deviation of the strength of the mortar cylinders. The standard deviation of the strength of concrete cylinders with $\frac{3}{4}$-aggregate was 6.0 per cent. It has been shown (1) that the standard deviation of the strengths of concretes and mortars is roughly proportional to the maximum size aggregate present. Since the standard deviation of concrete with $\frac{3}{4}$-in. aggregates is approximately 6.0 per cent, then the standard deviation of mortar with fine testing sand (maximum size approximately 0.03 in.) would be not more than 1 per cent. The tests, giving a standard deviation of 2.2 psi. (0.72 per cent) can therefore be regarded as representative.

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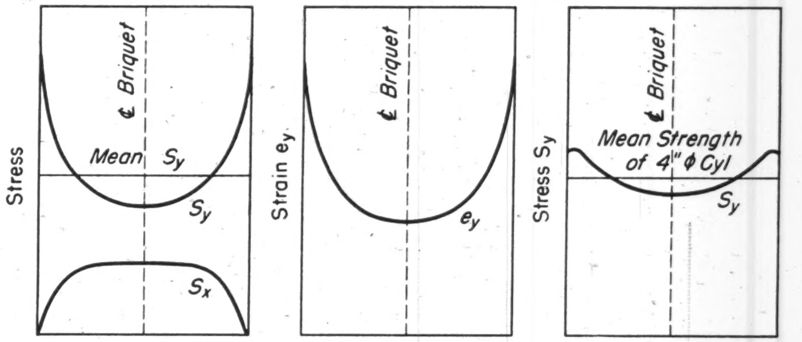
[5] Specifications for Gypsum Plasters (C 28 - 40), 1944 Book of A.S.T.M. Standards, Part II, p. 124.
Specifications for Gypsum Molding Plaster (C 59 - 40), *Ibid.*, p. 127.
Specifications for Gypsum Pottery Plaster (C 60 - 40), *Ibid.*, p. 129.
Specifications for Keene's Cement (C 61 - 40), *Ibid.*, p. 131.
Specifications for Calcined Gypsum for Dental Plasters (C 72 - 40), *Ibid.*, p. 133.



(*a*) Stress in briquet composed of material obeying Hooke's law.

(*b*) Longitudinal strain for condition at (*a*)

$$e_y = \frac{s_y - 0.2\, s_x}{E_c}$$

(*c*) Stress at failure according to statistical theory (see text).

FIG. 4.—Stresses and Strains in Transverse Midsection of Briquet.

Method of Statistical Analysis:

In order to facilitate the computations, the strength of the 4-in. diameter test cylinder has arbitrarily been set at 100, and all strengths and standard deviations have been expressed in terms of this value.

The standard deviation of the strength of the test cylinder σ_c was assumed to be the rounded value of 0.8 per cent of M_c, the mean strength of the test cylinder.

We have previously indicated that failure is assumed to occur in a section of the briquet which is 0.4 in. long and, therefore, will first compute the strength characteristics of a tension cylinder 4 in. in diameter and 0.4 in. long from the strength characteristics of the 4-in. diameter, 8-in. long specimen.

The long cylinder is 20 times the length of the short cylinder. If the short cylinder is taken as our unit length (7) then the long cylinder is $n = 20$ units in length. If σ_1 is the standard deviation and M_1 the mean strength of the cylinder of unit length, then from Tippett's tables (6, 7) for $n = 20$, we find that the mean strength of the long cylinder is $M_1 - 1.87\sigma_1$, and its standard deviation is $0.53\sigma_1$. The standard deviation of the long cylinder was assumed to be 0.8 per cent; hence 0.8 per cent $= 0.53\sigma_1$, or $\sigma_1 = 1.5$ per cent and the mean strength of the short cylinder is $M_1 - 1.87\sigma_1$, or 318 psi. (103 per cent) of the test cylinder, M_c.

For our analysis, we have considered the briquet to possess strength characteristics equivalent to those of a section 1 in. square and 0.4 in. long, in which the strain distribution is the same as at the midsection of the briquet. This section will be assumed to be composed of a number of small fibers. Forty fibers were selected as being adequate for our analysis. Thus, each fiber has a cross-section of 0.025 sq. in. The short cylinder has therefore the area of 500 such fibers.

In the weakest link theory, if the mean strength of the fiber is M_1, and its standard deviation is σ_1, then by Tippett's tables (6, 7) the strength and standard deviation of the strength of the group of 500 such fibers will be $M_1 - 3.04\sigma_1$ and $0.37\sigma_1$, respectively. Since the standard deviation of the strength of the short cylinder theoretically has been shown to be 1.5 per cent of M_c, then $1.5 = 0.37\sigma_1$, and $\sigma_1 = \frac{1.5}{0.37} = 4.05$ per cent of M_c. The mean strength (1.03 M_c) of the short cylinder is $M_1 - 3.04\sigma_1$. Hence the mean strength of the fiber $M_1 = 1.03\, M_c + 3.04\sigma_1 = 1.153\, M_c$.

On the other hand, by the combination theory, the standard deviation of the strength of the fiber is $1.5\sqrt{500} = 33.5$. Its mean strength will be 2.45 M_c as may be determined by using the values in Tippett's tables for $n = 500$.

Theoretical Strength of the Briquet:

Classic Maximum Stress Theory.—According to this theory, the test specimen fails when any point is stressed to the ultimate tensile stress, and consequently, no portion of the specimen is stressed beyond the tensile strength of the material. In Fig. 4(*a*) which presents the stress distribution across the briquet at midsection, the maximum stress at the waist of the briquet is 70 per cent greater than the mean stress, hence the strength of the briquet in a material obeying Hooke's law would be 59 per cent of the strength of the material, as determined in pure tension.

The longitudinal stresses in the plastic range were roughly estimated from those in the elastic range given in Fig. 4(*a*) as follows: The longitudinal stresses in Fig. 4(*a*) were computed for an extreme fiber stress of 400 psi., the assumed tensile strength of the material. The stresses were then multiplied by the ratio of stresses for a given strain according to Eqs. 2 and 1, or Eqs. 3 and 1, depending upon the assumed stress-strain relation.

If the material possesses the stress-strain characteristics of Eq. 2, the briquet would have a strength equal to 62 per cent and if the characteristics of the material were those of Eq. 3, then the briquet would have a strength equal to 66 per cent of the strength of the material as tested in pure tension.

Statistical Theory.—The strength of the briquet can be calculated on the basis of statistical methods by assuming that the briquet is composed of a number of fibers, the strength characteristics of which we have already computed. The probability of the fibers resisting the stresses imposed upon them by a definite loading is computed, and thus a strength-probability curve is determined. The mean strength and the standard deviation in the strength is then determined from this curve (3).

The strength which would be predicted by the weakest link theory has not been determined, preliminary computations showing it to be much below the true tensile strength of the material.

The strength of the briquet by the combination theory of strength has been computed on the assumption that the material obeys Hooke's law. The results are given in Table II. The percentage of the area of the cross-section of the briquet stressed beyond the tensile strength of the material is also given. The computations were made for each of three selected standard deviations in strength for the 4-in. diameter test cylinder. It is thus shown that the ratio of the strength of the briquet to that of the test cylinder will vary with the scatter in strength of the material. The scatter in strength will vary with a number of variables, in particular, with the size of aggregate (1); thus the aggregate size in a test mortar will affect the strength of the briquet. The computations show a briquet strength equal to 88 per cent of the strength of the tension test cylinder which had a standard deviation of 0.8 per cent, whereas the test results show that under these conditions the strengths would be approximately equal. The computed standard deviation of the strength of the briquet is $2\frac{1}{2}$ times the 10 per cent value which was determined experimentally.

TABLE II.—CALCULATED BRIQUET STRENGTHS.

Theory of Failure	Stress-Strain Relation	Stress Considered	Standard Deviation of Strengths of Cylinders σ_c in per cent of Mean Strength	Strength Ratio, Briquet/Cylinder	Standard Deviation of Strengths of Briquets σ_b in per cent of Mean Strength	Area of Briquet Stressed Beyond Tensile Strength, per cent
Classic	Hooke's Law (Eq. 1)	S_y	...	0.59	...	0
	Eq. 2	S_y	...	0.62	...	0
	Eq. 3	S_y	...	0.66	...	0
Combination Statistical	Hooke's Law (Eq. 1)	S_y	0.8	0.88	15	22
	Hooke's Law (Eq. 1)	S_y	2.0	1.00	30	36
	Hooke's Law (Eq. 1)	S_y	4.0	1.11	...	52
	Eq. 3	S_y	0.8	0.98	20	45
	Eq. 3	$S_y - 0.2\ S_x$	0.8	1.03	10.4	42
Test Results...			0.72	0.985	10	..

The strength of the briquet, as computed by the combination theory and the stress-strain relation of Eq. 3, is 98 per cent of the tensile strength of the material. This is an exact check upon experiment, but the computed standard deviation of the briquet strength is twice that found by experiment.

A final computation based on the combination theory has been made, in which the lateral stresses (s_x) were considered. Figure 4(*b*) gives the longitudinal strain, assuming Poissons Ratio (μ) = 0.2. A first approximation of the stress distribution beyond the elastic range was obtained by assuming that the longitudinal strain was equal to that as given in Fig. 4(*b*), and that the longitudinal stress for this strain is given by Eq. 3. The probability of failure of any fiber was assumed to be the same as that for a fiber equally strained by an s_y stress alone.

This computation gives results which closely approximate test results both for the mean strength and the standard deviation in strength. It may be noted that 42 per cent of the cross-section is stressed beyond the tensile strength of the material. The s_y stress distribution is given in Fig. 4(*c*).

It has been shown that statistical theory predicts that the mean stress at failure of the briquet is approximately the same as the tensile strength of the material.

The fact that the strength of the briquet may be a close approximation to the tensile strength of the material is in no way to be construed as a recommendation for the use of the briquet. On the contrary, the briquet should be discarded, if for no other reason than the ratio of briquet strength to tensile strength of the material is not constant, but depends on a number of factors, such as strength dispersion of the material, its stress-strain relation, and the effects of the volume changes with age, which are accentuated by the shape of the briquet.

COMPRESSIVE TEST CONCRETE CYLINDERS

It is our purpose here to point out the effect of tensile stress on the strength of concrete cylinders.

Filon (12) has shown that tensile stresses may be present in a very small volume distributed near the lateral surface and midlength of the cylinder, if the ends are restrained against lateral expansion. With completely restrained ends the tensile stresses are about 4 per cent of the numerical value of the mean compressive stress. The tensile strength of concrete nearly always is within the range of 6 to 15 per cent of the compressive strength; therefore, there is negligible chance that the failure of a concrete cylinder will be caused by tension. Because of the small volume in which tensile stress may occur, the probability that the cylinder would fail in tension is negligibly small even if the tensile strength were only 4 per cent of the compressive strength. This statement is based on the analysis of the beam and of the briquet, in which, at failure, it has been shown that stresses much in excess of the mean tensile strength were present in both specimens over a much larger portion of the volume than is subjected to tensile stress in the cylinder.

CONCLUSIONS

It has been shown that at the failure of nonuniformly stressed specimens high local stresses may be present in an appreciable volume of the specimen. These high local stresses may greatly exceed the strength of the same material as determined by testing specimens in which the stress is uniformly distributed.

The modulus of rupture of a concrete beam was computed according to a theory involving statistical considerations and found to be up to 90 per cent greater than the tensile strength of the material, with an ultimate strain in the extreme fiber of 1.84 times that for specimens subjected to uniform tensile stress. This is in much better agreement with the usual test findings than the strength computed by the classic theory of strength.

According to the classic maximum stress theory of strength a test briquet of mortar obeying Hooke's law will have a predicted strength of only 59 per cent of the true tensile strength of the mortar; in a briquet with a characteristic stress-strain diagram, the strength would be, by classic theory, 66 per cent of the true tensile strength.

Computations which involve statistical considerations show that, at an early age, the strength of a briquet might equal the true tensile strength of the material. However, the ratio of the strength of the briquet to the true tensile strength of the material is not a fixed quantity, but depends on a number of factors, such as the strength dispersion of the material and the degree to which the material approximates Hooke's law. Not only the strength but the strength distribution, as measured by the standard deviation as computed by statistical theory, agrees with test results.

It has been also demonstrated, even under test conditions which produce tensile stress in compression tests of concrete, the specimen will not fail in tension and the tensile strength of the material does not affect the compressive strength results. The same conclusion would apparently be valid for most other brittle materials.

Local stresses greatly exceeding the strength of the material may be present in test specimens such as beams and briquets for materials in which the strength dispersion is large. The closer the stress-strain relation of the material approaches Hooke's law, the higher these local stresses will be. For materials obeying Hooke's law, the local stresses in beams and in briquets may be as much as approximately 50 per cent greater than the tensile strength of the material. For concrete beams and mortar briquets, the local stress may be approximately 17 to 40 and 35 to 45 per cent higher, respectively, for beams and briquets, than the tensile strength of the material.

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(2) W. Weibull, "A Statistical Theory of the Strength of Materials," No. 151, *Proceedings*, Royal Swedish Institute, Eng.-Research (1939).

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(4) Phillip Turner, unpublished data.

(5) L. Schuman and J. Tucker, Jr., "Tensile and Other Properties of Concretes made with Various Types of Cements," *Research Paper 1552*, Nat. Bureau Standards, August, 1943.

(6) L. H. C. Tippett, "On the Extreme Individuals and the Range of Samples Taken from a Normal Population," *Biometrika*, Vol. 17, p. 364 (1925).

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(8) H. F. Gonnerman and E. C. Shuman, "Flexure and Tension Tests of Plain Concrete," *Proceedings*, Am. Soc. Testing Mats., Part II, Vol. 28, p. 527 (1928).

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(10) E. G. Coker, "The Distribution of Stress at the Minimum Section of a Cement Briquette," *Proceedings*, Internat. Assn. Testing Mats., Sixth Congress, New York, 1912, Paper No. XXVIII.

(11) E. G. Coker and L. N. G. Filon, "A Treatise on Photoelasticity," Cambridge Press, 1931, p. 580.

(12) L. N. G. Filon, "On the Elastic Equilibrium of Circular Cylinders under Certain Practical Systems of Load," *Philosophical Transactions*, The Royal Society of London, Series A, Vol. 198, 1902, p. 147.

DISCUSSION

Mr. W. S. Evans[1] (*by letter*).—Mr. Tucker's paper is very interesting and brings statistical methods into the field of physics or mechanics where, as yet, it is seldom seen. If the true tensile strength of concrete materials were as indicated by the briquet test or the cylinder test, and if the results of the beam tests as usually made and interpreted gave a real measure of the extreme fiber stress at bending, then Mr. Tucker's deductions would be more nearly correct and certainly more useful.

If a load could be applied with no eccentric effect to a concrete specimen whose shape was such that the effect of the load on all transverse planes in the minimum cross-section was uniform, by a gripping device which did not cause serious local effects, some small areas in some plane would undoubtedly fail before the specimen fails as a whole. When an area fails, which is so large or under such high stress that the stresses cannot readjust themselves, then the specimen fails. There is no question about the magnitude of this stress as given by Mr. Tucker. The question arises as to whether or not the theory will apply to the cement briquet. As stated by Mr. Tucker, Coker and Filon's work indicated that stresses near the edge of the briquet were 70 per cent higher than the average. Work by the writer[2] indicated higher stresses but both appear too high. Work by Matthew McNeary[3] involving large numbers of tests of a shape and in a device that should have given nearly even distribution of stresses indicated that 20 per cent might be more nearly correct. In any case, the most probable place for failure to start is in the areas of high stress and failure would start in these areas even though they were the strongest areas in the specimen. When large numbers are considered, the strongest fibers are as likely to be on the outside as on the inside and the variation would average out. It would appear that the average strength of mortar as indicated by the briquet test would be the apparent strength multiplied by some kind of a factor to account for the uneven distribution of stress. Call this factor 1.25 for the present.

The data which Mr. Tucker presents and the work by Gonnerman and Schuman referred to by Mr. Tucker indicate that the cylinder is equally as faulty as the briquet and what has been said of the latter also applies to the cylinder. Less is known about the cylinder and hence a factor to cover the effects of gripping can hardly be estimated.

A beam test is also difficult to make and interpret. Loading at the third points causes the moment to be uniform and the shear to be zero over the middle third of the beam. This is an advantage. However, the ratio of length to depth and the effect of concentrated loads may be questioned. The effect of a concentrated load is to decrease the fiber stress due to bending on the opposite side of the beam. The stress pattern must be complicated and could be determined best by photoelasticity. However, attempts to apply the theory of elasticity[4] indicate that 20 per cent is a conservative estimate. Since most of this reduction is due to a reduction in bending moment the stress as computed from the various stress-strain relations assumed by Mr. Tucker would also be about 20 per cent too large. If the break occurs at or between loads, shear may be neglected.

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[1] Professor of Civil Engineering, University of Maine, Orono, Me.

[2] Paul Cloke and W. S. Evans, "Needed Improvement in the Cement Briquet Testing Apparatus," ASTM Bulletin, No. 104, May, 1940, p. 31.

[3] Matthew McNeary, "A Comparison of Standard and Proposed Tension Grips and Test Pieces for Testing Portland Cement Mortars," Bulletin No. 39, Maine Technology Experiment Station, University of Maine, Orono, Maine.

The results on Fig. 2 of Mr. Tucker's paper show that a bending moment which would cause a maximum fiber stress of 400 psi. using his Eq. 3 and the classic method, would indicate a modulus of rupture (Mc/I) of 450 psi., an increase of $12\frac{1}{2}$ per cent. Now combine this relationship with the short beam effect and the known variation in the briquet and see what happens.

Let it be assumed that a briquet shows a strength of 400 psi. which means that the outside fibers must have been capable of resisting 480 psi., a stress which the extreme fibers in a beam of the same material should resist. This would correspond to a modulus of rupture of 648 psi. as ordinarily computed, taking into account the length of beam and stress-strain relationship assumed above. The explanation is as follows: If the modulus of rupture is 648, the moment (M) from which this is computed is 648 × S ($S = I/c$ for the beam). Assuming M to be correct, the fiber stress should have been $\frac{8}{9}$ of this or 576 psi. Taking into account the length of beam and effect of load concentrations, the M was actually $\frac{5}{6} \times 648\ S$ and the actual fiber stress was $\frac{5}{6} \times 576 = 480$ psi. which the mortar in the briquet should stand. In other words, mortar, the apparent strength of which is 400 psi. when tested as a briquet will resist an apparent bending moment which gives a modulus of rupture of 648 psi. The ratio here is 1.62, a commonly experienced value. All relationships applied have considerable experience and physical theory to back them up.

The writer has done considerable statistical work himself and thoroughly believes in it. In this case, however, it is felt that the distribution of stress governs the strength of concrete specimens and this distribution is not a matter of chance. Variability in the material can be overcome only by better methods of fabrication and by averaging large numbers of tests.

MR. JOHN TUCKER, JR. (*author's closure by letter*).—The object of the paper was to demonstrate, with the aid of statistical methods, that stresses greater in magnitude than those usually considered as the (tensile) strength of the material may be present in a specimen at failure.

Mr. Evans' discussion substantiates this finding, even for the elongated briquet, whose use was suggested by Coker and Filon.[5]

The concentrated loads applied in the testing of beams at third points, as Mr. Evans cites, causes the stresses to differ from those computed by usual methods. This subject has been considered.[6] The stress in the extreme tension fiber (between load points) will be increased up to 3 per cent, not decreased by 20 per cent as Mr. Evans claims. The modulus of rupture of a beam of the depth to span ratio used in our paper according to statistical theory will be decreased by the small amount of about 1.5 per cent.

The analysis of the paper was not based on tensile strengths of specimens gripped laterally, but upon specimens in which the load was applied through bolts embedded in the ends. Thus values closely approximating the true tensile strength of the material were obtained.

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[4] S. Timoshenko, "Theory of Elasticity," McGraw-Hill Book Co., Inc., New York, N. Y., 1934, p. 95.

[5] E. G. Coker and L. N. G. Filon, "Photoelasticity," Cambridge University Press, Cambridge, England, 1931.

[6] Discussion of paper by John Tucker, Jr., "Statistical Theory of the Effect of Dimensions and of Method of Loading upon the Modulus of Rupture of Beams," *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 1089 (1941).

EFFECT OF LENGTH ON THE STRENGTH OF COMPRESSION TEST SPECIMENS

BY JOHN TUCKER, JR.[1]

SYNOPSIS

When compression test specimens of concrete are shorter than twice their least width it is customary to adjust the test values by the use of a single set of correction factors, such as those in Standard Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (C 42 – 44),[2] the corrections depending only upon the ratio of length to least width. This paper demonstrates that the extent of the variation in strength with length is dependent upon several distinct factors. For example, the relation between strength and slenderness of specimen varies with the strength of the concrete and therefore the use of a single set of correction factors is not warranted. Much more reliable estimates of strength may be obtained by limiting the range of slenderness values to those for which the correction is small, even though this may require diameters less than those usually considered acceptable. Although the numerical values which are given apply to concrete, the principles are applicable to other brittle materials.

The increase in strength with decrease in the length-diameter ratio of compression test specimens of brittle materials is a phenomenon well known and well substantiated (**1, 2, 3**).[3] A.S.T.M. Standard Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (C 42 – 44)[2] gives factors to correct the strengths of concrete specimens of any length-diameter ratios from 0.50 to 1.75 to that of a standard length-diameter ratio of 2.0.

It is the purpose of this paper to show that the reduction in strength with increase in length-diameter ratio may be divided into three regions, in each of which there is a separate cause for the reduction. Figure 1 shows the typical observed variation in compressive strength with length-diameter ratio.

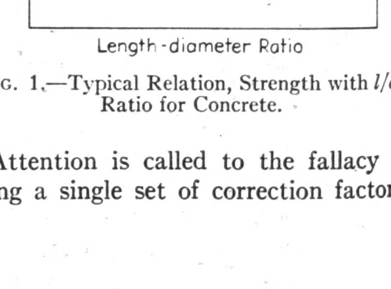

FIG. 1.—Typical Relation, Strength with l/d Ratio for Concrete.

Attention is called to the fallacy of using a single set of correction factors, since, as will be shown, a separate set of factors is required for concrete of every strength. It is suggested that the ratio of the lengths of the specimens to their diameters, or their l/d ratios be limited between certain values which could be easily secured and for which the correction would be small. This limitation in the l/d ratio of the specimen may entail the use of specimens with diameters less than has been considered the minimum; the use of such specimens is shown to be sound.

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[1] Chief, Cement and Concreting Materials Section, National Bureau of Standards, Washington 25, D. C.

[2] 1944 Book of A.S.T.M. Standards, Part II, p. 460.

[3] The boldface figures in parentheses refer to references at end of paper, p. 984.

LONG COLUMN SPECIMEN: REGION OF FAILURE BY BUCKLING

Test specimens that are sufficiently long and slender fail by buckling. This method of failure falls in the first of the three regions into which failures are segregated. This region is that for specimens with length-diameter ratio greater than that indicated by B in Fig. 1. Such specimens are not within the scope of the present paper and will not be considered further.

SHORT COLUMN SPECIMEN: INTERMEDIATE REGION OF FAILURE

In brittle materials, there is a least length at which buckling will occur; specimens shorter than this will fail by shear in a plane inclined to the axis. According to the ordinary theory, for lengths between the minimum at which buckling will occur and the length where the shear failure becomes restrained because of the shortness of the specimens, the strength will be constant. Short columns fall in the second region, indicated by the limits of A and B in Fig. 1. The point A at which shear failure becomes restrained corresponds to a specimen length of approximately 1.5 times the diameter, the exact value depending upon the material.

In the following analysis, attributed originally to Coulomb, the shearing stress on a given inclined plane is assumed to be the summation of a frictional force per unit of area and an effective shearing stress in that plane. Let us consider a prism taken from the cylinder, 1 in. in thickness, and with the base 1 in. square. We then have the condition illustrated in Fig. 2. While the force f_c on the base (of unit area) of the prism is therefore a stress, the equilibrant f_c on the inclined face AC (area = sec α, hence greater than unity) is the total force, and not a stress. The component of the equilibrant f_c acting in the plane AC is expressed as follows:

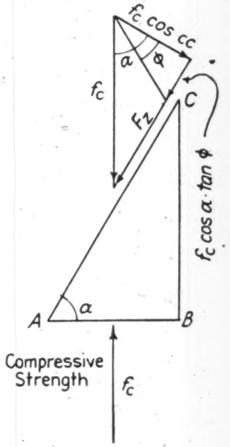

FIG. 2.—Shearing Stress in Plane Inclined at Angle α.

$$f_c \sin \alpha = F_z + f_c \cos \alpha \cdot \tan \phi \ldots\ldots (1)$$

where:

$F_z = f_z/\cos \alpha$ (shearing stress times area AC)

and α = the inclination of the plane,

ϕ = the hypothetical angle of friction,

f_z = the effective shearing stress on the section, and

f_c = the compressive stress on the specimen.

Consequently:

$$f_s = f_c\,(\sin\alpha\cdot\cos\alpha - \cos^2\alpha\cdot\tan\phi)\ldots(2)$$

Differentiating gives:

$$\frac{df_s}{d\alpha} = f_c\,(\cos^2\alpha - \sin^2\alpha + 2\cos\alpha\cdot\sin\alpha\cdot\tan\phi)$$

$$\text{Setting } \frac{df_s}{d\alpha} = 0\text{, to find } f_s \text{ maximum}$$

and solving for tan ϕ, and setting $\alpha = \alpha_0$ for the plane of maximum shear, we get

$$\tan\phi = \frac{\sin^2\alpha_0 - \cos^2\alpha_0}{2\cos\alpha_0\cdot\sin\alpha_0} =$$

$$-\frac{\cos 2\alpha_0}{\sin 2\alpha_0} = -\cot 2\alpha_0\ldots\ldots(3)$$

From this we get

$$\alpha_0 = 45° + \phi/2\ldots\ldots\ldots\ldots(4)$$

Equation 4 has been applied (4) in the determination of the friction angle ϕ, by measurement of α_0, the angle of shear. These investigations have measured α_0 the angle of rupture, and computed ϕ to be between 20 and 30 deg. An accurate measurement of the shear angle is difficult, particularly so for concrete, because of the highly irregular and uneven surface of fracture. In the opinion of the author it is impossible, even approximately, to determine the shearing angle for concrete by direct measurement. It appears to be greater than 60 deg. with a corresponding value for ϕ of 30 deg. It would appear, however, from the analysis of the failure of the shorter, restrained, specimen, given later, that a value of $\phi = 15$ deg., with corresponding $\alpha_0 = 52.5$ deg. is more representative.

It can readily be seen that the shortest specimen in which an unrestrained shear failure can occur has an l/d ratio of tan α_0. We have therefore d tan 52.5 deg. $= 1.3\,d$ as the length of such specimens.

In specimens whose length exceeds the quantity $d \tan\alpha_0$, the inclined plane of shear failure may vary in position along the axis for a length equal to the quantity $l_0 = l - d\tan\alpha_0$. In considering two groups of specimens of one diameter and different lengths, both greater than $d\tan\alpha_0$, the quantities l_0 for each are designated as the excess lengths, and the shorter one as the unit excess length.[4] The longer specimens will then contain n units of excess length.

If σ is the standard deviation of the strengths and M the mean strength of the shorter specimen, then the mean strength and the standard deviation of the strength of the longer specimen may be found, under the numerical value for n as given in Tippet's tables (5, 6). It may be noted that n need not be an integer. Fractional values of n may be found by interpolation in the tables. Thus, for example, if $\tan\alpha_0 = 1.3$, and we are comparing specimens of length diameter ratios of 3.3 and 6.3, the net lengths of the specimens would be $3.3 - 1.3 = 2.0$ and $6.3 - 1.3 = 5.0$, respectively. The unit excess length would be 2, and the value of n, for the longer specimen, would be $2.5\left(=\dfrac{5.0}{2.0}\right)$.

The reduction in strength with decrease in length has been determined experimentally by a number of investigators. We have selected the data of Gonnerman (2), Hutchinson (1), and Johnson (3). It is noted that of the three sources of data, Gonnerman's results were given for the greatest range of values of l/d in the region of short-column specimens. Although Hutchinson's data are quite comprehensive for

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[4] Theoretically the unit excess length should be of the magnitude such that the distribution of the strengths of the specimens are normal. The distribution of the strengths of longer specimens will be skew, the longer the specimen, the greater the skew. Actually the distribution of the strengths of test specimens does not depart appreciably from the normal form. Therefore the numerical value which may be selected as the unit excess length is arbitrary.

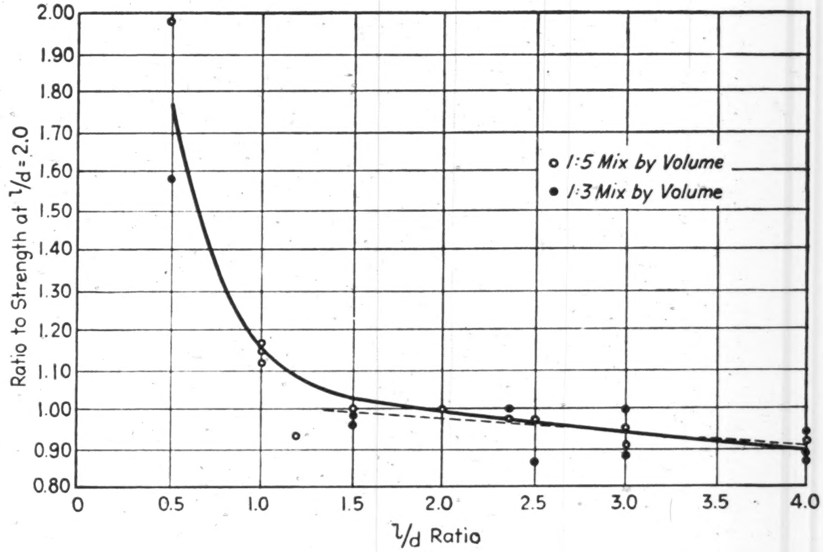

FIG. 3.—Data by Gonnerman on Effect of Length on Strength.

l/d values ranging from 0.5 to 2.17, it may be noted that they afford only the limited range of approximately 1.3 to 2.17 for our present analysis. Johnson's data are restricted to the range in *l/d* values of 1.00 to 2.83.

Gonnerman's data are illustrated in Fig. 3. The straight dotted line in Fig. 3 drawn through points for $l/d \geqslant 1.2$, was determined by the author, using the method of least squares.

TABLE I.—STRENGTHS RELATIVE TO THE STRENGTH OF SPECIMENS WITH $l/d = 2.0$.

l/d	Standard Method C 42-44	Gonnerman Data			Hutchinson[c]	Johnson[c]
		Gonnerman's Curve	Author's Line of Best Fit	Column 4 Adjusted[b]		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.5........	1.041	1.025	0.991	1.016	1.04	1.04
2.0........	1.00	1.00	0.975	1.00	1.00	1.00
2.17.......	0.987[a]	0.991	0.970	0.995	0.992	0.99
3.0........	0.926[a]	0.945	0.942	0.967	0.964[a]	0.955[a]
4.0........	0.862[a]	0.900	0.910	0.933	...	...

[a] Extrapolated.

[b] Author's curve adjusted to correspond to strength of 1.00 for $l/d = 2.0$, by dividing values in Column 4 by 0.975.

[c] Best representative (curved) line as determined by the author from the original data.

Table I gives the relative strengths of concrete specimens having lengths from 1.5 to 4.0 diameters, as determined by Gonnerman, Hutchinson, and Johnson. The values attributed to Hutchinson and Johnson are from curves determined by the author, which differ to a small extent from those offered in the original papers.

Table II gives the reduction in strength according to statistical theory, and the reductions as found by Gonnerman, Hutchinson, and Johnson. In computing the theoretical reduction in strength with increasing length, the specimen with $l/d = 2.0$ has been chosen as that having the unit excess length. Thus, $2.0 - 1.3 = 0.7$ is the unit excess

TABLE II.—THEORETICAL AND OBSERVED REDUCTIONS IN STRENGTH.

l/d	*n*	Theoretical Reduction in Strength	Observed Reduction in Strength, per cent		
			Gonnerman[a]	Hutchinson	Johnson
2.0........	1		0	0	0
3.0........	2.4	0.7σ	3.3	3.6	4.5
4.0........	3.9	1.02σ	6.7	...	...

[a] Table I, column 5.

length, and specimens with $l/d = 3.0$ and 4.0, respectively, will have excess lengths of $\frac{3.0 - 1.3}{0.7} = 2.4$ and $\frac{4.0 - 1.3}{0.7} = 3.9$ units. The theoretical reductions in Table II were obtained by interpolating in Tippet's table (5), (6).

From Gonnerman's data, Table II, at $l/d = 3.0$ we find a theoretical reduction of 0.7σ corresponds to an observed reduction of 3.3 per cent, and the standard deviation σ would be $\frac{3.3}{0.7} = 4.7$ per cent. At $l/d = 4.0$ we find 1.02σ corresponds to an observed reduction of 6.7 per cent, hence the standard deviation σ would be 6.6 per cent. The actual standard deviation of the strengths of Gonnerman's test cylinders is unknown; therefore, the substantiation of the theory in this case lies in the values of 4.7 and of 6.5 per cent being in no way discordant with ordinary findings.

In Hutchinson's tests, the strength reduction, by increase in l/d from 2.0 to 3.0 is 3.6 per cent. This corresponds to a standard deviation in strength of 5 per cent ($0.7\sigma = 3.6$, $\sigma = \frac{3.6}{0.7} = 5.0$ per cent). This is a value that is within the range to be expected.

Using Johnson's data, however, we are in a better position, as he gives the scatter in strengths in the form of the mean deviations. The standard deviation σ, computed from the mean deviation, at $l/d = 2$, is 4.5 per cent. In Table II we find that the specimens with $l/d = 3$ will be reduced by the value of 0.7σ and in Johnson's tests the actual strength reduction is 4.5 per cent. Thus $0.7\sigma = 4.5$ per cent or $\sigma = 6.5$ per cent, compared to the experimental 4.5 per cent reduction. Or, inversely, with a scatter in strength of $\sigma = 4.5$ per cent for specimens with $l/d = 2.0$, we should have a reduction of $0.7\sigma = 0.7 \times 4.5 = 3.2$ per cent in strength, compared to the reduction of 4.5 per cent which was found.

The one instance that we have in which there are some data on both the strength dispersion and the reduction in strength gives experimental and computed values of 4.5 and 3.2 per cent, respectively, for the reduction in strength. These may be considered but a rough approximation. However, when we consider the experimentally reduced strength of 95.5 compared to the theoretical value of 96.8 per cent the check upon theory appears more convincing. We must remember that tests of this nature are subject to innumerable variables which tend to vitiate the results obtained by computation. The hypothesis postulates that all specimens are made of a uniformly heterogeneous material. This ideal is far from being achieved in specimens of concretes fabricated in different heights, with resultant differences in water gain on the upper surface. Johnson (3) attempted to eliminate this by fabricating the specimen on its side, but introduced another variable in that the material was not uniform in planes parallel to the axis of loading. The scatter of the points which are averages of all specimens of one length from the curve representing Johnson's data for all sets of tests, indicates the many uncertainties present in such an intricate study.

We have shown that a reduction in strength is to be expected from the statistical theory of the strength of materials, and the strength reduction experimentally observed is of the same order as that predicted by the theory. The reduction in strength, by statistical theory, is a function of the size of the specimen, the maximum size of aggregate in the mix, and undoubtedly other variables.

SHORT SPECIMEN: REGION OF RESTRAINED FAILURE

As shown previously, the shortest specimen in which unrestrained shear failure may occur has a length $l = d \tan \alpha_0$ if the ends of the specimen are completely restrained.

For lengths less than $d \tan \alpha_0$ it may be assumed that failure occurs in the plane or planes which intersect one upper edge of the specimen, and the opposite lower corner. The angle of inclination of this plane to the horizontal is less than α_0. The conditions of equilibrium of Fig. 2 still hold, and Eq. 2 is valid. If we now set $f_z = f_z$, or the shearing strength of the material, we find

$$f'_c = \frac{f'}{\sin \alpha \cdot \cos \alpha - \cos^2 \alpha \cdot \tan \phi} \quad \ldots . (5)$$

In which f'_c is the compressive strength of the specimen of height $l = d \tan \alpha_0$.

The relative strength of specimens for lengths $l = d \tan \alpha$ where $\alpha < \alpha_0$ may now be computed. The theoretical variation in strength with length of short specimens has been computed for several values of the friction angle ϕ and given in Fig. 4.

Figure 5 shows the two extreme curves and an intermediate curve which represent three of Hutchinson's eight concretes. Each curve represents the eight specimens of varied lengths made from a concrete of one nominal strength. The strength of the concretes in specimens with $l/d = 2.0$ are given in the figure. The specimens varied in length from 0.5 d to 2.17 d.

It is obvious, by comparing Figs. 4 and 5, that the family of theoretical curves in Fig. 4 is of the same general

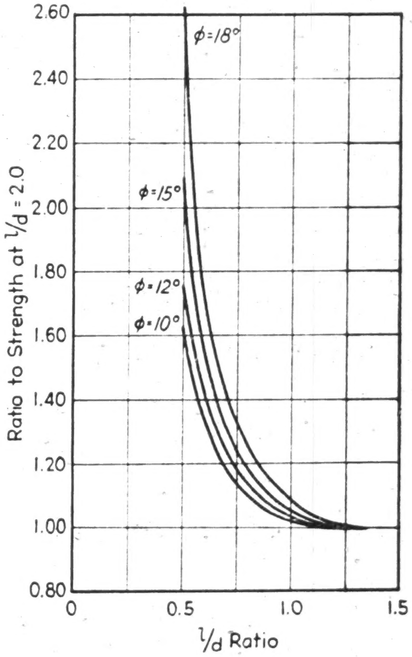

FIG. 4.—Theoretical Increase in Strength with Decrease in Length.

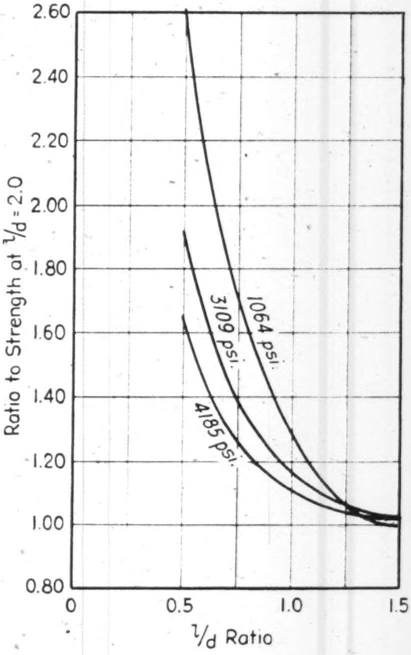

FIG. 5.—Relation of Strength to Length for Concretes of Several Strengths.

form as the family of experimental curves in Fig. 5. Although there is not an exact fit of any theoretical with any experimental curve, a theoretical curve with some selected value of ϕ may be chosen which will approximate one of the experimental curves. We may also cite here that the experimental values from which Hutchinson's curves are drawn are sufficiently erratic so that only the approximate shape of the curve is known. There are many factors that tend to affect the strength, particularly of the shorter specimen, and make a precise determination of the strength-length curve impractical.

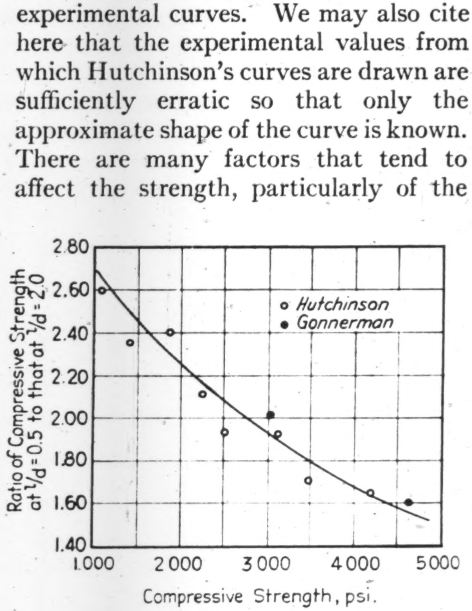

FIG. 6.—Effect of Strength of Concrete upon the Ratio of Strengths of Specimens at $l/d = 0.5$ an $l/d = 2.0$.

It is immediately apparent from Fig. 5 that the increase in strength with decrease in l/d ratio is markedly higher for weaker than for stronger concretes. To demonstrate the effect of the strength of the concrete upon the strength increase by shortening of the specimen, Fig. 6 has been prepared. In this figure, the abscissas are the strengths of each of the concretes in specimens having a length of twice the diameter; the ordinates are the ratio of the strengths at $l/d = 0.5$ to that at $l/d = 2.0$. The two values available from Gonnerman's data shown in Fig. 3, are given, as well as all of Hutchinson's. The values from Hutchinson's data are those from the curves representative of the eight points for each concrete; for Gonnerman's points, the actual ratios of the observed strengths at each length are given.

From Fig. 6 it is obvious that there is a regular relation between the nominal strength of the concrete and the strength increase caused by shortening the specimen. The two values by Gonnerman are consistent with the relation shown by Hutchinson's tests.

DISCUSSION

It has been shown that, in the two regions of l/d ratios considered, different factors determine the apparent increase in strength with decrease in l/d ratio, each factor being operative only in its own region. In the region of shortest lengths (below approximately $l/d = 1.3$) the change in strength is caused by the restraint developed by the angle at which failure may occur. The increase in strength caused by shortening the specimen is a function of the nominal strength of the concrete. In the intermediate region the strength reduction is essentially attributable to the strength dispersion of the material.

Since there are distinct factors causing strength change with length in the two regions, and furthermore since in the shortest length region, $l/d = 1.3$, the strength increase varies markedly, depending upon the strength of the concrete, it appears highly desirable to limit the l/d ratio to the intermediate region. Limits of 1.5 to 2.0 for the l/d ratios are suggested.

The variation in strength between values of l/d from 1.5 to 2.0 is not more than 4.0 per cent; the average reduction, from data by Gonnerman, Hutchinson, and Johnson, is 3.2 per cent. If the reduction for this difference in length were to be set as 3 per cent, then the error left after any correction for length would be not more than 1 per cent. When compared to the accuracy to be expected from tests of field cores with heights approximately equal to their diameters, where the unevenness of the base brings in an added uncertainty of the l/d ratio, and consequent uncertainty in the correction factor to be applied, the limitation of the l/d ratio between 1.5 and 2.0 makes for a decided increase in the accuracy of the results.

The use of an l/d ratio of 1.5 or more for cores taken from pavements and slabs, which may be not more than 6 in. and in some cases not more than 4 in. in depth, would require that the cores be as small as 4 in., or even 2½ in. in diameter. There has been reluctance to accept such small specimens, although A.S.T.M. Method C 42 accepts cores three times the diameter of the largest size aggregate. We should differentiate between an acceptable ratio of the diameter of largest size aggregates to the dimensions of the space in which it may satisfactorily be placed, and the acceptable ratio between these quantities for cores cut from a concrete. As Gonnerman states, for facility in placing the concrete the largest size of the aggregate should be limited to one third to one fourth the diameter of the cylinder and even aggregate one half the diameter can be placed satisfactorily, although with difficulty. The size of aggregate would, by reason of facility in placing, be limited by the slab thickness—for a 6-in. slab, the coarse aggregate would not be over 2 in.; in a 4-in. slab, not over the 1½-in. size. Such sizes would not be excessive in the 4-in. and 2½-in. diameter cores suggested at the beginning of the paragraph.

In another paper (6) it has been demonstrated that aggregate as large as one half the width of the specimen may be used, and that specimens as small as 1 in. square prisms, 2 in. high, containing ½ in. aggregate, gave satisfactory results.

The benefit of limiting the length of test specimens to a ratio of between 1.5 and 2.0 is demonstrated. The strength of a specimen with $l/d = 1.5$ should be reduced 3 per cent to give an equivalent strength for $l/d = 2.0$. This limitation of l/d would in some instances necessitate the use of cores with comparatively small diameters. The previous paper (6) has shown that the specimens with smaller diameters will have greater strength dispersion, but gives rules for the selection of an adequate number of specimens to give the same precision as that possessed by a given number of larger specimens.

SUMMARY

1. The variation of strength in the short compression test specimen may be separated into two regions:

(*a*) The restrained failure region, where the length of the specimen is less than that to permit the failure to occur at its natural inclination to the axis. In this region the increase in strength with decrease in length differs markedly with the strength of the concrete under test.

(*b*) The short-column region, where the reduction in strength with increase in length is a function of the standard deviation of the strength of the concrete, which is a function primarily of the size of the largest aggregate.

2. By limiting the length of the concrete specimens between 1.5 to 2.0 diameters, the maximum correction of 3 per cent will reduce the apparent strength of a specimen 1.5 diameters long to the strength of the standard specimen 2 diameters long.

3. The use of small specimens in which the diameter is not less than twice the size of the largest aggregate permits the taking of cores with lengths of at least 1.5 diameters from any structure.

4. Although the numerical values which are given apply to concrete, the principles are applicable to other brittle materials.

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METAL CLEANING: I—INDIRECT PERFORMANCE TESTS*

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The consideration of methods and specifications for the field of metal cleaning is a complicated one because of the variety of metals and metal finishes, as well as the infinite variety of soiling agents which may be encountered. It has been suggested that specifications for metal cleaning and metal cleaners may best be developed by investigating each problem individually. Ultimately this line of attack will be followed, but a knowledge of available evaluation methods could simplify the problem materially.

This paper has been prepared in order to provide information regarding suggested or currently used evaluation tests in readily available form. Although some one test may be suggested as suitable, specific conditions may invalidate it, and other conditions may have to be observed. Consequently, the various information given in this paper should in no sense be considered as a recommendation, since no specifications have as yet been developed. In fact, it is hoped that this publication will result in constructive criticism which will further the work of Section G on Metal Cleaners of Subcommittee II on Specifications of Committee D-12 on Soaps and Other Detergents.

Evaluation Methods

The evaluation of metal cleaners is complicated by the fact that it is not always possible to make pilot plant or full-scale trials, and, when the evaluation is made in a laboratory other than that of a specific plant, there is considerable doubt regarding either the specific soil used in the removal tests, or the utility of a metal cleaning composition for any than the specific soil upon which the cleaner was tested.

There are two general methods of evaluation approach:

I. Indirect performance tests including analyses may be developed, or, more directly,

II. Soil removal performance methods may be employed.

This paper is concerned with the indirect method of approach, which is the logical one in the absence of knowledge of the soil, standard or otherwise, to be removed and of the conditions under which the cleaner may be used. A later paper will deal with the second general method as Part II of this discussion.

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Even though a well-defined soil and method of removal may be available, indirect chemical or physicochemical methods may be of decided value in defining qualities desired in a cleaning bath. Such methods will serve to differentiate between products which might otherwise prove closely similar under the soil removal method, and will assure desirable properties not otherwise measurable. Such methods may also prove useful in control of the cleaning baths.

Before an examination of the indirect performance tests is made, it is pertinent that the general metal cleaning processes be examined to determine in a general way what conditions and materials may be encountered.

CLEANING PROCESSES

Metal cleaning processes may arbitrarily be classified as follows (**98**):[2]

1. Wiping (by hand or machine).
2. Brushing (by hand or machine).
3. Sand blasting.
4. Tumbling.
5. Hydraulic spraying.
6. Steam gun spraying.
7. Dipping in still tank.
8. Machine washing.
9. Electrolytic cleaning (anodic or cathodic).
10. Continuous acid or alkaline dip.
11. Vapor degreasing.
12. Solvent degreasing.

To this may be added (**91**):

13. Emulsion degreasing:

(*a*) Organic solvent containing oil-soluble emulsifying agent.

(*b*) Organic solvent containing oil-soluble emulsifying agent mixed with kerosene and solvent to form emulsion.

General Types of Cleaning:

The main general types of cleaning, however, may be reduced to the following:

1. Soak tank cleaning.
2. Mechanical tank or spray cleaning.
3. Electrolytic cleaning (anodic, cathodic, alternate current).
4. Solvent or vapor degreasing.
5. Emulsion degreasing.

The requirements of these types of cleaning will define the specifications of the detergents used therein. Consequently analytical methods or performance tests may be developed which will cover certain of the requirements of the above cleaning methods.

PERFORMANCE TESTS

The more generally investigated performance tests are:

pH and titration values,
Colloidal properties,
Water softening,
Conductivity,
Solvent action,
Surface and interfacial tension measurements,
Emulsification,
Rinsability, and
Stability under conditions of usage.

The initial approach to this problem is to ascertain the availability of methods for analysis, specifications, and performance methods such as those listed above.

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[2] The boldface numbers in parentheses from Nos. 1 to 209 refer to the "Annotated Bibliography of Aluminum Cleaning," ASTM BULLETIN, No. 120, January, 1943, p. 33; No. 121, March, 1943, p. 33; and No. 128, May, 1944, p. 35. References from No. 210 on are appended to this paper. A combined bibliography is included in the A.S.T.M. Standards on Soaps and Other Detergents (1944). (Issued as separate publications.)

ANALYTICAL METHODS

Many metal cleaning compositions may be analyzed by standard procedure used for alkalies, but where mixtures of materials are used which may comprise caustic alkalies and the many alkaline salts, soap, rosin, synthetic wetting agents and detergents, corrosion inhibitors and sulfonated oils, difficulties will be encountered with standard procedures. No attempt has been made extensively to cover the literature on this subject, but a method (**135**) has been developed for the determination of caustic soda, soda ash, trisodium phosphate and sodium sulfate in the presence of the others. Standard Methods of Chemical Analysis of Sulfonated and Sulfated Oils have been published by the Society (**210**). Methods of Chemical Analysis of Industrial Metal Cleaning Compositions (**167**) have also been published by the Society. The latter reference covers the only series of methods especially designed for the examination of metal cleaning compositions, and is valuable where chemical control of purchases is desired and where the utility of a material for plant use has already been proved. No value would accrue from attempts to cover these methods in detail since they are readily available and are self explanatory.

Methods for Sampling and Chemical Analysis of Special Detergents (caustic soda and the alkaline salts) is another A.S.T.M. standard (**211**) of potential value to the metal cleaning trade.

Methods of chemical analysis and control can be used in defining the quality of chemicals purchased as such, rather than in mixtures, and considerable effort has led to specifications for many of these agents.

SPECIFICATIONS

Chemical specifications are available (**63, 3, 212**) for many of the individual alkaline salts and for organic solvents used in metal cleaning, and can be of considerable use in the purchase of materials used in the cleaning department.

Chemical analysis and specifications may be of considerable value in controlling the quality and purchase of cleaning compositions or their constituents, but leave much to be desired in the use evaluation of such materials or their mixtures. The literature reveals many attempts to measure the properties of cleaning compositions and clearly indicates the necessity for so doing if optimum cleaning results are to be attained. There are many phases to such evaluation, so that for purposes of simplification they have been condensed wherever possible.

The performance tests which follow are from the sources indicated, and are what seem to be the methods most applicable to metal cleaning control. While there may be so-called "simple" tests which seem to be suitable for evaluation, the chances are that these "simple" tests fail to control certain important factors, resulting in data which are in grave error. On the other hand, the refinements of technique obtained through the use of complicated or expensive equipment are not indicated where the art has not progressed sufficiently that the data obtained have significant effect upon the end results.

pH AND TITRATION VALUES

Many cleaning compositions are alkaline in nature and possess properties which are easily measured. The earlier control work on cleaning baths was carried out by determination of the relative alkalinity of the bath by titration methods (**33, 47, 54, 101, 107, 116**). Differentiation may be made between active and inactive alkali by titration methods (**116**), and has been also used for control by the laundry industry for many years. Unfortunately, alkalinity is not necessarily a means for comparison between two alkalies or products to be used for cleansing, since each material will have its own degree of soil removal activity regardless of difference in alkalinity characteristics.

Another indication of relative strength of alkalinity is measurement of hydrogen-ion (pH) concentration, which has become increasingly simple and accurate (**47, 54, 97, 101, 107, 116**). Unfortunately, neither titration values nor pH values are a full indication of utility. However, a combination of the two is highly useful. Of even greater value is determination of the buffering action of a material, since if a material had high initial pH value but this value is susceptible to marked changes either with a small amount of acidic material or changes markedly upon dilution, it could be expected that the bath efficiency might drop markedly. A highly buffered material is then one which maintains nearly its initial pH value over a considerable range, either upon the addition of acid or alkali to it, or upon dilution. Such information is highly valuable, and can readily be determined by titrating a standard solution of the mixture with a standard solution of acid or alkali, measuring the pH values at given intervals of addition.

That such values are of importance in specifications for metal cleaning compositions is indicated by the fact that several Federal specifications (**213, 214, 215, 216**) require such measurements.

In general there are two systems available for pH measurement; these are either colorimetric or potentiometric. For many purposes the colorimetric method may be suitable, and either paper or liquid indicators covering the pH range are available. Presence of interfering substances may dictate the use of one indicator over another. It is a desirable precaution to check the colorimetric indicator against the potentiometric system since the presence of certain chemicals may lead to error. The potentiometric means for pH measurement presents the choice of a variety of equipment. In general the glass electrode system has proved most readily useful since they may be used under a variety of conditions such as high temperature and high pH work, but where so used, the proper corrections must be made.

Titration of alkaline or acid solutions is the time-honored method for estimation for strength of solution, and differentiation between "active" and "inactive" alkali may be made by choice of indicator (phenolphthalein and methyl orange, respectively).

In the evaluation of an alkaline or acidic material it may be advantageous to prepare a pH-titration curve. In doing so, due care should be used in the choice of solution strength and in the rate of addition of acid (or alkali) that the deflection points are fully covered.

COLLOIDAL PROPERTIES

The colloidal properties of the various alkaline salts vary immensely. The importance of colloidal dispersion (**81, 101, 116**) of soil or its adsorption (**101**) and peptization (deflocculation) (**45, 101, 105, 117**) has not been overlooked, and methods for measurement are to be found in two Federal specifications (**217, 218**). In general, materials exhibiting any detersive action will tend to disperse carbon or other particles, though it may be difficult to differentiate between the means for producing the effect whether it be adsorption, peptization, or deflocculation.

Numerous investigators in the detergent field have tested the deflocculating action of soaps, alkalies, and wetting agents against carbon black. The test may be carried out in various ways, of which the following is representative (**218**):

> 0.250 g. of Norit carbon (SAU-30 or C grades) must be wet out by 50 ml. of the 4:100 dilution within 10 min., when the test is made as follows: Place the carbon in the bottom of a dry 1-in. test tube. Using a 50-ml. pipette, transfer the solution into the bottom of the test tube, holding the pipette against the side of the test tube. Withdraw the pipette gently and note the time for carbon to wet out spontaneously and motion to cease. The tube must now appear black throughout. Shake the tube. At the end of 24 hr. of standing, there must still be carbon held in suspension.

WATER SOFTENING

Another important property of the agents used in metal cleaning is to condition the water, either by softening it (**75, 116**) by forming a soluble complex with the calcium and magnesium ions present, or by forming soluble or insoluble calcium and magnesium salts of the compound in use. The presence of synthetic detergents in metal cleaning compositions introduces considerable difficulty in the usual water-softening determination, since soluble calcium and magnesium compounds may be formed obscuring the usual lather end point. But with this interference recognized, a water softening test is used for evaluation in a number of Government specifications (**216, 217, 219**).

One performance test of marked importance in alkaline solutions, especially in areas where hard water is used, is their resistance to decomposition by the hard water elements. In the first place hard water should be softened through their use, and the amount of agent required for the softening action should be a minimum, since the balance of the agent used will presumably be employed in soil removal.

The use of synthetic detergents has complicated the picture somewhat, since many of them are essentially unaffected by hard water, whereas soap readily forms troublesome, insoluble, and oftentimes sticky curd. This would seem to indicate the use of one of three tests: (1) when soap and synthetic agent are absent, (2) when soap alone is present, and (3) with synthetic detergent alone or admixed with soap.

A suitable test (**213**) for use in the absence of synthetic wetting agent or detergent and soap follows:

> *Preparation of Standard Hard Water.*—Transfer to a 500-ml. graduated flask the calculated amount of reagent-grade cal-

cium acetate, monohydrate (accurately weighed and based on an accurate determination of its calcium content), equivalent to 0.4275 g. of calcium carbonate. Dissolve in distilled water from which carbon dioxide has been removed by boiling, make up to 500 ml. with CO_2 free water, and mix. (One milliliter of this solution should contain the equivalent of 0.855 mg. of calcium carbonate.) Prepare a 5 per cent solution of the detergent under test by dissolving a 50-g. portion of the well-mixed sample in distilled water (heat may be used if necessary); cool to room temperature, make up to a liter with distilled water, and mix. Transfer 50 ml. of the standard calcium acetate solution to a 250-ml. volumetric flask, add 100 to 150 ml. of CO_2 free distilled water (depending upon the volume of detergent solution to be added); then add the concentrated detergent solution in the amount recommended for 250 ml. of water having a hardness of 10 grains (171 parts per million) per gallon, and dilute to the mark with distilled water from which the carbon dioxide has been removed by boiling. This solution now contains the equivalent of 10 grains per gallon of calcium carbonate and the recommended amount of detergent to be used for water of this hardness.

NOTE.—In adding the detergent solution, use a graduated pipette and shake the bottle containing the solution so that any undissolved portion will be uniformly distributed throughout the solution.

NOTE.—Most hard waters contain both calcium and magnesium as the hard water constituents, and it is generally conceded that the chloride and sulfate, respectively, are most suitable.

Water-Softening Capacity.—Prepare 250 ml. of water containing the equivalent of 10 grains per gallon of calcium carbonate and the recommended amount of detergent as described above. Heat this solution to a temperature of 155 F. and stir vigorously to distribute any precipitate. Without cooling, pipette 50 ml. into a 250-ml. Pyrex glass-stoppered, round bottle at room temperature. Add 1 ml. of the American Public Health Association's standard soap solution,[3] shake vigorously, let stand (with bottle on its side) for 5 min., and again shake vigorously. A continuous lather that persists over the whole surface for 5 min. or more after the second shaking indicates that the water has been softened completely.

A test designed to estimate the ability of an agent to prevent precipitation of calcium and magnesium compounds follows (216):

Standard Soap Solution.—The Standard soap solution employed shall be as specified by the American Public Health Association.[3]

Calcium and Magnesium Chloride Solution.—Prepare a solution in distilled water, containing calcium chloride and magnesium chloride equivalent, respectively, to 9.37 mg. of calcium carbonate and 6.50 mg. of magnesium carbonate per ml. This solution should be prepared by dilution of more concentrated stock solutions of calcium chloride and magnesium chloride which have been accurately analyzed. The deviation from the specified concentrations should not exceed 1 part per 100.

Lime Soap Dispersion Test.—Pipette 100 ml. of stock solution of the sample and 100 ml. of distilled water into a 250-ml. beaker. Pipette 2 ml. of standard soap solution into the beaker containing the solution of the sample and stir until the solution is mixed. With constant stirring, slowly add 2 ml. of standard calcium and magnesium chloride solution, measuring the volume accurately by means of a 2-ml. pipette. Cover the beaker with a watch glass and heat in an oven at 60 ± 5 C. for 30 min. Remove the solution from the oven, cool to room temperature, and filter through a prepared and weighed asbestos felted Gooch crucible. Wash the beaker and precipitate with several small portions of hot water, transferring the precipitate quantitatively to the filter. The total volume of wash water used should not exceed 25 ml. Dry the crucible and contents at 100 to 105 C. Cool the crucible in a desiccator and weigh. Drying and weighing should be repeated until the difference between successive weights is not greater than 0.3 mg.

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[3] Standard Methods for the Examination of Water and Sewage, Eighth Edition, American Public Health Assn.

CONDUCTIVITY

The property of conductivity may be of especial interest in metal cleaning by electrochemical means (**48, 81, 101, 174**). The greater the degree of conductivity, in general, the greater the evolution of gas and the more rapid the cleaning process. It is indicated that the current-carrying capacity is of more importance for steel cleaning than for the softer metals where less vigorous action is required. Foam is a problem in electro cleaning, and conductivity measurements alone are not a sufficient means for evaluation. However, a convenient laboratory setup for the evaluation of such metal cleaners has been developed (**174**).

Conductivity may readily be measured by means of a conductivity bridge (**235**) and suitable cell. The results as obtained may be expressed as specific conductivity. Precautions should be taken with a series of comparison samples to adjust them to constant temperature.

SOLVENT ACTION

Certain types of soil may most effectively, safely, or economically be removed by solvent or vapor-degreasing (**1, 10, 11, 15, 21, 34, 44, 45, 58, 60, 76, 94, 98, 137, 138, 144, 146, 149, 152, 183, 185, 187, 188**), or by emulsion degreasing (**41, 91, 98, 139, 185**). Several Federal Specifications are concerned with organic solvents for solvent or vapor degreasing (**220, 221, 222, 223, 224**) and with emulsion degreasing (**225, 226, 227, 228, 229, 230**).

It is apparent that solvent action can best be determined by actual trial. A specific example (**221**) follows:

Oil Removing Properties.—A 3 by 6-in. anodized aluminum alloy panel shall be coated with S.A.E. No. 50 oil, and completely immersed in the solution. The time required to remove the oil shall be observed.

SURFACE AND INTERFACIAL TENSION MEASUREMENTS

Most effective cleansing is generally obtained when the wetting of the surface being cleansed, or surface or interfacial tension of the cleaning solution is maintained at an optimum (**10, 13, 45, 101, 189**). The wetting efficiencies of cleaning solutions has been determined by the drop method (**93**) but a quicker and more generally reliable method is through use of the DuNouy tensiometer. The concept of reduction of interfacial tension between cleaner solution-oil interfaces (**8, 82, 105**) suggests its measurement as a means for evaluation and control. This end may be accomplished by using a stalagmometer, but more readily by using the interfacial type of the DuNouy tensiometer.

Various methods for the determination of surface or interfacial tensions have been used in Federal specifications (**214, 215, 217, 218, 219, 231, 232**).

Measurement.—Surface tension can be measured in a number of ways, for example by capillary rise or by the drop weight method, but both of these methods require considerable care in manipulation. One of the simplest and most rapid method of measurement is the use of the DuNouy tensiometer. This method is required by numerous Government specifications. Ordinarily the measurements are made either at a single concentration (that recommended by the manufacturer of the cleaner) or at a series of concentrations, preferably under controlled temperature conditions.

Calibration of the DuNouy instrument (**237**) is easily accomplished, and where high accuracy is desired, correction factors have been developed (**238**).

Interfacial tension measurements can be determined in several ways among which the stalagmometer method and the DuNouy ring method are probably the most popular. Again the DuNouy apparatus is the most rapid means for measurement, though the determination is somewhat more difficult than for surface tension against an air interface. It has been the custom in these laboratories to use Nujol as the oil involved, though where a specific oil is encountered in a plant, this could as readily be used.

EMULSIFICATION

An indication of the ease of emulsification is the interfacial tension measurement of the cleaner solution against an oil, preferably that to be removed. More direct indications (**10, 33, 45, 84, 101, 105, 117**) of emulsifying ability are obtained by actually determining the emulsifying activity of the cleaner solution and the degree of stability of the emulsion produced.

The ability of the emulsion degreasing agents to remain in suspension is an important factor in proper cleansing and tests for estimation of this characteristic are given in several Federal specifications (**227, 228, 229, 230**).

Emulsion stability of solvent emulsion type cleaners (**230**) is ascertained by dilution of the cleaner with solvent and then with water and recording the degree of "creaming" or breakdown of emulsion. Stability of emulsion formation has been tested (**228**) by adding a given volume of lubricating oil to the emulsion cleaner in an open Petri dish.

A recently developed centrifugation method (**236**) can be used for a quantitative estimation of emulsion stability.

In the evaluation of emulsion cleaners it is important that the detergent be stable to water, and to extreme dilution with Stoddard solvent, kerosine or other organic solvent used.

When soak cleaner baths are used it is likewise important that adequate emulsification be produced, since otherwise the greases, oils, and other contaminants removed might float to the surface of the bath and contaminate the piece being cleaned at the time it is withdrawn to the rinse tank.

Therefore two general types of test are indicated: One to determine the stability of emulsion cleaners to dilution and to water, and another for aqueous cleaning baths either upon dilution, or overloading of the bath. It has been suggested (**75**) that emulsifying power may be ascertained by using butter fat as the oil phase and determining stability of emulsion. Another suggestion (**107**) is that the emulsifying power of a cleaning bath be evaluated by adding known increments of either mineral oil or lanolin to the bath in question, bringing about emulsification then permitting the baths to stand and observing them for separation. Still another suggestion

(**116**) for evaluation is to measure the time for removal of mineral or vegetable oils from brass disks under controlled experimental conditions.

A suggested stability test for emulsion cleaners (**230**) follows:

Stability of Emulsion.—Place 5 ml. of the material into a 50-ml. graduated cylinder having a ground glass stopper. Add 45 ml. of kerosine (kerosine shall be in accordance with Federal Specification VV-K-211). Stopper cylinder and shake thoroughly. Maintain temperature conditions at 70 to 90 F. The material shall readily disperse or dissolve in the kerosine to give a clear liquid without the presence of undissolved matter. Pour 5 ml. of the thinned material into another similar graduated cylinder and add 45 ml. of distilled water. Stopper and shake thoroughly. A creamy emulsion shall result. Allow to stand undisturbed for 24 hr. at temperature conditions of 70 to 90 F. Examine the cylinder after this period. There shall be not more than 10 per cent "creaming" (floating or settling out of a layer of emulsion) with no breakdown of the emulsion.

A further test of emulsion cleaners (**228**) utilizing addition of an oil to indicate stability follows:

Homogeneity.—Place 20 ml. of the cleaner in a 4-in. Petri dish. Add to this, without agitation, 5 ml. of Grade S.A.E. No. 70 lubricating oil or No. 6 fuel oil. Run the test at room temperature. The oil shall be completely dispersed throughout the cleaner. Swirl for a moment or two and place the solution in an open Petri dish. Examine after 48 hr. at room temperature. A homogeneous solution shall be formed which shall show no separation.

A test (**107**) utilizing the observation of emulsion stability can be carried out as follows:

Emulsion Stability.—Prepare a 30 per cent by weight solution of commercial lanolin in mineral spirits or Stoddard solvent. Add 5 ml. of this solution at room temperature to 95 ml. of cleaner solutions at varying concentrations. Homogenize in a standard manner, transfer to a 100-ml. graduated cylinder and note the time for separation of oil globules.

RINSABILITY

The function of a detergent is to assist in the removal of soil from the surface to be cleansed. To be a suitable detergent and to leave a perfectly clean, unaffected surface, the cleansing agent should preferably be unreactive with the surface being cleansed, should not be adsorbed by the surface, hence should rinse freely. There are many cases where reaction with the surface being cleansed may be both desirable and beneficial, but these are special cases, and most generally no remaining detergent is desired. The importance of rinsing tests has been mentioned (**101, 105, 116**) and a number of Federal specifications contain tests designed to measure this property (**213, 214, 221, 225, 231, 232, 233, 234**).

The ease of rinsability of the numerous compositions used for metal cleaning may vary widely, even though thorough rinsing may have an important bearing upon subsequent processing. It is a fairly well-known fact that chemicals have varying degrees of affinity for metal or other surfaces. What is often termed "chemical cleanliness" may be a misnomer, since a chemical film, possibly of monomolecular thickness, may be retained on the surface cleaned. It has even been suggested that absence of "water break" may be due to such a film which is easily wet by water.

Since ease of rinsability and relatively complete freedom from contaminant from the cleaning bath is desired, suitable tests should be available for determining this factor.

Two specifications (**214, 232**) contain the same test for rinsability:

> *Test for Rinsing Properties.*—Completely suspend for 5 min. a 4- by 6-in. glass panel in a beaker containing 1 liter of solution of the stripper, maintained at 85 to 95 C. Remove and dip completely twice in a beaker containing 1 liter of tap water at 70 C., allowing to drain 10 sec. between dips. Observe presence or absence of "water breaks." Allow to dry for 2 hr. at room temperature at an angle of 45 deg. Observe any evidence of residue. Add a drop of c.p. alcohol to the surface, allow to evaporate, and notice any evidence of a white deposit. The absence of "water breaks" at the dip, and of a residue on drying, and the failure to form a white deposit on evaporation of the alcohol, shall indicate a suitably clean surface.

Two other specifications (**231, 233**) give essentially the same test except for variations in concentration and temperature of cleaner, and the fact that the test panels are permitted to dry for 15 min. prior to water rinsing.

It may be possible to utilize a contact resistance measurement (**186**) in the determination of cleanliness.

STABILITY UNDER CONDITIONS OF USAGE

The usual difficulty with a laboratory method of evaluation is that no attempt is made to exhaust the bath, measuring the ability of the detergent to withstand long usage, heat, aeration, sedimentation, and perhaps overloading of the bath with oils and soil. The need for such a test is evident (**101, 107, 116, 117, 189**), but development of a suitable test to evaluate this property is difficult because of the many types of soil and operating conditions involved.

SUMMARY

It is to be understood that none of the foregoing tests are to be considered as recommended methods. Many of them simply are in use in certain specifications as a means for controlling some desired quality. The object in reviewing these test methods is to make them available for future use, to indicate the extent to which such tests are resorted to in defining qualities of cleaning compositions, and, if possible, to develop constructive criticism.

Cleaning processes are classified as these general types:

1. Soak tank cleaning.
2. Mechanical tank or spray cleaning.
3. Electrolytic cleaning.
4. Solvent or vapor degreasing.
5. Emulsion degreasing.

Available analytical methods and specifications are outlined.

The performance tests which are considered, and their general applicability, follow:

pH and Titration Values.—Methods and equipment readily available and satisfactory.

Colloidal Properties.—Tests are available, but are very specific in character.

Water Softening.—Methods are available for soap or soapless composition, but tests in the presence of synthetic foaming agents have not been developed.

Conductivity.—Methods for measurement are available, and a practical method for test can be used.

Solvent Action.—This is a specific property but apparently of considerable value.

Surface and Interfacial Tension.—Equipment is available and can be used as a means for controlling the amount of surface-active agent present.

Emulsification.—Tests for this property are very specific though apparently of considerable value.

Rinsability.—This property is very important and many tests have been devised, but is difficult to measure suitably (considering the multitude of possible surfaces).

Stability Under Conditions of Usage.—It appears that short of actual trial there is no readily applicable general tests for this quality of a bath.

There are a number of performance tests already in use which may be applicable either directly or with alteration to define desired properties of cleaning compositions and it is not suggested that these can be used as the sole criterion of utility.

REFERENCE

(210) A.S.T.M. Standard Method of Chemical Analysis of Sulfonated and Sulfated Oils (D 500 — 41), 1944 Book of A.S.T.M. Standards, Part III, p. 984.

(211) A.S.T.M. Standard Methods of Sampling and Chemical Analysis of Special Detergents (D 501 — 43), 1944 Book of A.S.T.M. Standards, Part III, p. 976.

(212) Book of A.S.T.M. Standards, Part III.

(213) Detergents, Special; (for Aluminumware, Dishwashing Machines, and Manual Cleaning), Federal Specification P-D-236, November 18, 1941.

(214) Cleaner, Alkaline, Heavy Duty. TAC ES-No. 382b. July 12, 1943, Tank-Automotive Center, Tentative Specification.

(215) Compound, Cleaning; Aircraft. No. 20015-B, October 12, 1940. Air Corps Specification.

(216) Detergent, Dishwashing. Bureau of Ships, Specification 51D8 (INT) March 15, 1943.

(217) Polyether, Phenyl Sulfonate Sodium Salt. Navy Aeronautical Specification M-363a, January 27, 1941.

(218) Ether, Alkylated, Phenolic (for Cleaning Aircraft). Navy Aeronautical Specification RM-70, February 7, 1938.

(219) Compound, Vapor Cleaning. Tank-Automotive Center Tentative Specification TAC ES-No. 542b, May 1, 1943.

(220) Compound, Paint Stripping, Non-Inflammable, Navy Aeronautical Specification C-113, Amendment 2, September 7, 1942.

(221) Compound, Engine Cleaning and Paint Stripping, Navy Aeronautical Specification C-114, Amendment 1, March 10, 1942.

(222) Trichlorethylene, Stabilized, Army-Navy Aeronautical Specification AN-O-T-631a, Amendment 1, May 2, 1942.

(223) A.S.T.M. Standard Specifications for Stoddard Solvent (D 484 - 40), 1944 Book of A.S.T.M. Standards, Part III, p. 81.

(224) A.S.T.M. Standard Specifications for Petroleum Spirits (Mineral Spirits) (D 235 - 39), 1944 Book of A.S.T.M. Standards, Part III, p. 84.

(225) Compound, Carbon Removal, for Aircraft Engine Parts, Navy Aeronautical Specification C-118, May 16, 1942.

(226) Compound; Carbon Removal (for Engine Parts), Army Air Forces Specification No. 20025, June 15, 1942.

(227) Solvent, Degreasing, Self-Emulsifying, Tank-Automotive Center Tentative Specification TAC ES-No. 398b, May 10, 1943.

(228) Cleaner, Carburetor, Tank-Automotive Center Specification TAC ES-No. 645a, March 17, 1943.

(229) Corrosion Prevention; Processing and Packaging, Ordnance Dept. Tentative Specification TM 38-305, August 1, 1943.

(230) Compound; Grease-Cleaning, Solvent Emulsion Type, Federal Specification P-C-576, November 6, 1942.

(231) Cleaner, Metal, Silicate-Soap, Navy Aeronautical Specification C-109a, March 31, 1942.

(232) Paint, Stripper, Alkali, Tank-Automotive Center, Tentative Specification TAC ES-No. 452b, August 3, 1943.

(233) Compound, Paint Stripping (Silicate Type) Navy Aeronautical Specification C-67d, March 4, 1943.

(234) Compound, Cleaning: For Painted Surfaces, Bureau of Ships ad interim Specification 51C20 (INT), March 15, 1941.

(235) Industrial Instruments, Inc., Jersey, City, N. J.

(236) R. C. Merrill, Jr., "Determining the Mechanical Stability of Emulsions," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, pp. 743–746 (1943).

(237) "Cenco-duNouy Tensiometers," *Bulletin 101*, Central Scientific Co., Chicago, Ill.

(238) W. D. Harkins and H. F. Jordan, "A Method for the Determination of Surface and Interfacial Tension from the Maximum Pull on a Ring," *Journal*, Am. Chem. Soc., Vol. 52, pp. 1751–1772 (1930).

METAL CLEANING: II—SOIL REMOVAL PERFORMANCE METHODS*

BY JAY C. HARRIS[1]

Cooperators:

Claudius Nielson, Nielco Laboratories; B. S. Van Zile, et al., Hercules Powder Co.; C. S. Lowe, Pennsylvania Salt Manufacturing Co.; R. S. Frazer and M. P. Boland, Cowles Detergent Co.; A. H. Baldwin, Hansen-Van Winkle-Munning Co.; and C. C. Ross, U. S. Naval Engineering Experiment Station.

It is not the purpose of these papers on metal cleaning to suggest either that direct performance methods, or laboratory soil removal evaluation tests should be considered the only criteria for choice of cleaner: They are intermediate evaluation or control methods. The only true method to provide a significant answer for final choice is to determine how effectively and economically actual soil is removed in plant practice over a period of time and under adequate control. It is the purpose of these papers to provide pertinent data on evaluation methods so that improved laboratory technique may result, with the ultimate object of providing improved cleaners for commercial usage. Consequently none of the indirect performance tests nor the soil removal tests to be described should in any sense be considered as "standards" of the society.

These papers are necessary to a thorough evaluation of present technique and it is hoped that their publication will result in constructive criticism which will further the work of Section G on Metal Cleaners of Subcommittee II on Specifications of the A.S.T.M. Committee D-12 on Soaps and Other Detergents.

The indirect approach to the metal cleaning problem by measurement of physical, chemical, or physicochemical properties of a cleaning composition was dealt with in Part I of this paper.[2] The present portion of the paper will attempt to cover the direct evaluation of metal cleansers by measurement of their relative ability to remove a given soil by laboratory methods. This approach yields an immediate answer, when applied to soiled surface in question, but may leave unanswered the problem of whether such a composition will remove a soil of other, perhaps quite dissimilar, characteristics. The factor of the soil chosen for such a method of evaluation then becomes most important.

The types of soil or foreign matter

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* Also published in ASTM BULLETIN, No. 136, October, 1945, p. 31.

[1] Chairman, Section G on Metal Cleaners, Subcommittee II on Specifications, Committee D-12 on Soaps and Other Detergents; Monsanto Chemical Co., Dayton, Ohio.

[2] Jay C. Harris, "Metal Cleaning: I—Indirect Performance Tests," see p. 985.

generally encountered have been classified (**94**):[3]

1. Mineral oil blanking lubricant.
2. Pure oil of a compounded type used in drilling and tapping, or on automatic screw machines.
3. Soap emulsions used in milling, blanking, pressing, etc.
4. Heavy soap-base drawing compounds.

Other soiling materials may comprise:

5. Buffing compound constituents.
6. Graphite drawing compounds.
7. Carbonized oils, greases, or food products.
8. Asphaltic and tarry materials.
9. Corrosion products deposited on, or from the metal being cleaned.
10. Food residues, beer-stone, milk-stone, etc.
11. Paints, varnishes, waxes, etc.

From the variety of materials listed it is apparent that the soil present may have considerable bearing upon the cleaning method and materials chosen. This is not the only criterion used in a choice of method, since the metal surface being cleansed may be important. Perhaps the most important factor, however, is choice of method to remove the specific soil from the specified metal adequately, at minimum cost.

A condensed classification of the different cleaning methods follows:

1. Soak tank cleaning.
2. Mechanical tank or spray cleaning.
3. Electrolytic cleaning.
4. Solvent or vapor degreasing.
5. Emulsion degreasing.

Use of this classification in combination with knowledge of the type of soil present, and ease of its removal, is a more logical approach to the problem, since several general types or even combinations of types of cleaning may advantageously be used.

Since one or more of these cleaning methods may be used, the need is thus exemplified for some means for evaluating these methods either on a semi-plant scale, if available, or in the laboratory. Resort to semi-plant or laboratory scale evaluation will eventually lead to a desire for more uniformly soiled pieces for trial purposes which in the semi-plant scale may mean segregation of representative pieces from stock. The laboratory is not always so fortunately situated, and desire for uniformity of test results almost invariably leads to application of a soil under more or less well-controlled conditions of application, dependent upon analysis of the problem and knowledge of the resultant effects.

Application of a "standard" soil implies perfect control of all factors involved, as well as full control of all subsequent operations, since the ultimate object of such a test leads to the desire to obtain reproducible results of known variability.

Faced with the many types of soil which must be removed, we might at once arrive at the deduction that no "standard" soil or "standard" test could be devised. The fact that many investigators have published results with one or another type of soil, however, only emphasizes the need for such a test or tests. Unfortunately, many such papers fail to outline fully test conditions and few make any attempt to indicate the sensitivity and reproducibility of their chosen method of operation. Such criticism leads to the suggestion that available information be correlated, so that all pertinent data be tabulated for ease of comparison.

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[3] The boldface numbers in parentheses from Nos. 1 to 209 refer to the "Annotated Bibliography of Aluminum Cleaning," ASTM BULLETIN, No. 120, January, 1943, p. 33; No. 121, March, 1943, p. 33; and No. 128, May, 1944, p. 35. References from Nos. 210 to 238 are appended to "Metal Cleaning: I—Indirect Performance Tests," see p. 985. References Nos. 239 to 243 are appended to the present paper.

The published laboratory methods for soil removal evaluation were arbitrarily classified on the basis either of the method for soil removal, or upon the soil itself:

A. Oil removal,
B. Solvent emulsion method,
C. Electrolytic method,
D. Carbon removal,
E. Friction removal, and
F. Paint stripping.

Though this classification may overlap, and does not represent all the available procedures, the methods of operation used for one type may be applicable, under altered conditions, to another type of cleansing.

No attempt has heretofore been made to evaluate the available methods dealing with soil removal from metal surfaces. This paper therefore makes an attempt to subject them to such an analysis, and to make them available so that they may be studied and improvements in technique applied. There is ample room for research in the field of laboratory evaluation, but fortunately for industry, metal cleaning as an art has kept in pace with developments in metal fabrication.

It should be emphasized that none of the methods described is recommended by Section G, but that this information was required before any attempt at cooperative effort could be made.

The evaluation of the methods follows this general outline:

Soil:
  Kind

  Application
    1. Preparation of Panels
    2. Method
    3. Aging Period
    4. Deviation

Cleaning Technique:
  Metals
    1. Kind
    2. Panel Size

  Solution
    1. Amount of Detergent
    2. Volume
    3. Temperature
    4. Time
    5. Agitation
    6. Replicates

  Method

  Rinsing
    1. Time
    2. Temperature
    3. Volume
    4. Agitation
    5. Method
    6. Test for Effectiveness

  Drying
    1. Temperature
    2. Time

Measurement of Soil Removal:
  Method
  Sensitivity

The information covered by this outline was not always available but has been made as complete as possible.

METHOD A--OIL REMOVAL

METHOD A-1

The method described by Morgan and Lankler (156, 157) follows:

Soil:

Kind.—Unspecified mineral oil composition used in rolling brass containing an unspecified amount of Fluorescent Oil Green H. W.

Application.

1. *Preparation of Panels.*—The metal test strips, 5 by 10 cm. (2 by 4 in.) in size are scrubbed by hand with a 0.50 per cent solution of Nacconol NR at 110 F., thoroughly rinsed in warm water, rinsed in alcohol, and allowed to dry.

2. *Method.*—Strips of wool flannel 4.7 by 9.7 cm. (1.875 by 3.875 in.) are saturated with a mineral oil composition such as is used in the rolling of brass. These oil-saturated wool strips are alternated with the metal strips to form a stack with protecting metal plates and oil-saturated wool strips above and below the stack of experimental strips.

The stack of plates is placed between the jaws of a hydraulic press, the edges of the stack of plates being carefully squared up. A pressure of 35 kg. per sq. cm. (500 psi.) is applied, and the pressure maintained until no more oil oozes out from the edge of the stack, the edges being constantly wiped with a clean cotton cloth. At the end of this process the pressure is released, and the strips are removed and retained in a perfectly horizontal position until taken out of the stack, one at a time, for the cleaning experiment.

3. *Aging Period.*—Not specified. Apparently to be used at once.

4. *Deviation.*—Average is 7.3 per cent by weight, present in 0.000113 g. per sq. cm., average for ten panels.

Cleaning Technique:

Metals.

1. *Kind.*

Steel: 20-gage cold-rolled sheet.
Galvanized steel: 20-gage, hot-dip-galvanized
Tin-plated steel: 24-gage dairy plate
Aluminum: Alloy 3S (1.2 per cent manganese), 20-gage, mirror finish
Brass: Soft brass sheet, 0.032 in. thick, Rockwell F hardness 61 to 62 annealed at about 550 C.

2. *Panel Size.*—2 by 4 in. (5 by 10 cm.).

Solution.

1. *Amount Detergent.*—0.5–10.0 per cent.
2. *Volume Solution.*—800 ml. in 1-liter beaker.
3. *Temperature.*—Variable.
4. *Time.*—Variable.
5. *Agitation.*—None.
6. *Replicates.*—Unspecified, but apparently single test.

Method.—The panels were fully immersed in the detergent solution, as in "soak" tank cleaning.

Rinsing.

1. *Time.*—1 min.
2. *Temperature.*—100 F.
3. *Volume.*—Unspecified. Running water.
4. *Agitation.*—Running water.
5. *Test for Effectiveness.*—None.

Drying.

1. *Temperature.*—Room.
2. *Time.*—Unspecified.

Measurement of Soil Removal:

Method.—Panels examined visually, or photographed under ultraviolet light.

Sensitivity.—Checked by gravimetric oil determinations. Minimum amount of oil detectable was 0.000004 g. per sq. cm.

METHOD A-2

The Nielco Laboratories method of evaluation follows:

Soil:

Kind.—S.A.E. 50 Lubricating oil (paraffin base).

Application.

1. *Preparation of Panels.*—None.
2. *Method.*—Immerse in S.A.E. 50 lubricating oil. Pennsylvania. Remove. Drain 1 hr.
3. *Aging Period.*—1 hr.
4. *Deviation.*—Not given.

Cleaning Technique:

Metals.

1. *Kind.*—Steel, aluminum.

2. *Panel size.*—2½ by 3 in.

Solution.

1. *Amount Detergent.*—0.9 to 3.3 per cent.
2. *Volume Solution.*—1000 ml.
3. *Temperature.*—Boil.
4. *Time.*—Variable.
5. *Agitation.*—None, other than boiling liquid.
6. *Replicates.*—Two, in same bath, held in unspecified manner relative to one another.

Method.—The panels were fully immersed in the detergent solution as in "soak" tank cleaning.

Rinsing.

1. *Time.*—Unspecified.
2. *Temperature.*—Cold.
3. *Volume.*—Unspecified; apparently from tap.
4. *Agitation.*—Unspecified; apparently from tap.
5. *Test for Effectiveness.*—Water break. See under separate "Rinsing Test."

Drying.

1. *Temperature.*—Unspecified.
2. *Time.*—Unspecified.

Measurement of Soil Removal:

Apparently by water break. Tests followed by plant trials.

Rinsing Test:

Glass panel 3½ by 5 in. dipped in the hot alkali cleaning solution for 5 min. Remove and rinse immediately in cold water. Allow to dry for 2 hr. Examine for any film left on panel. Add to panel 1 drop of alcohol and allow to evaporate. If no deposit is noted, compound is considered as free rinsing and the surface clean.

METHOD A-3

Rinker (243) evaluated metal cleaning compositions in the following manner:

Soil:

Kind.—Mineral oils 100 and 200 viscosity, mineral oil and 15 per cent fatty acid, mineral oil and 1.5 per cent and 5 per cent calcium soap, mineral oil and 10 per cent and 20 per cent sodium soap, sulfur-base mineral oil and protective lanolin film.

Application.

1. *Preparation.*—Anti-rust oil or surface film removed.
2. *Method.*—Panels dipped individually in the oils.
3. *Aging Period.*—Two weeks.

Cleaning Technique:

Metals.

1. *Kind.*—Cold-rolled steel.
2. *Panel Size.*—3 by 6 in.

Solution.

1. *Amount Detergent.*—6 oz. per gallon.
2. *Volume Solution.*—Sufficient for total immersion.
3. *Temperature.*—200 F.
4. *Time.*—3, 6, 9, 12, and 15 min.
5. *Agitation.*—Provided by heating at 200 F.
6. *Replicates.*—Several, but unspecified.

Method.—The panels were totally immersed in the cleaning solution as in "soak" tank cleaning.

Rinsing.

1. *Time.*—Not specified.
2. *Temperature.*—Not specified.
3. *Volume.*—Not specified.
4. *Agitation.*—Shower spray.
5. *Acid Dip.*—5 per cent sulfuric acid solution followed by further shower spray.

Drying.—Not indicated.

Measurement of Soil Removal:

Method.—Absence water break.

METHOD A-4

The Hercules Powder Co. method as described by Van Zile and coworkers which is a variation of the Morgan and Lankler method, is as follows:

Soil:

Kind.—100 viscosity Coastal Natural Mineral Oil (Sinclair Refining Co., Marcus Hook, Pa.).

Application.

1. *Preparation of Panels.*—Sheet steel (20-gage) strips 1 by 2 in. in size are dipped in carbon tetrachloride, sanded with waterproof Tri-M-ite paper (manufactured by Minnesota Mining and Manufacturing Co., St. Paul, Minn., designa-

tion 400-A-soft back), dipped in carbon tetrachloride, and dried in an oven at 80 C.

2. *Method.*—Strips of (80 by 80) cotton print cloth, ⅞ by 1⅞ in. are saturated with the 100 viscosity oil, to which is added 1 g. of Fluorescent Oil Green HW 185 per cent to 100 cu. cm. of oil.

Balance of preparation as described by Morgan and Lankler.

Cleaning Technique:

Metals.

1. *Kind.*—Steel, 20-gage.
2. *Panel Size.*—1 by 2 in.

Solution.

1. *Amount Detergent.*—1 to 10 per cent.
2. *Volume Solution.*—125 ml. of solution in 150-ml. beaker.
3. *Temperature.*—80 C.
4. *Time.*—1 to 10 min.
5. *Agitation.*—None.
6. *Replicates.*—Apparently four are used.

Method.—Operated as a soak bath,[4] in which strips are hung from hooks.

Balance of method as described by Morgan and Lankler.

Rinsing.—In a stream of distilled water.

Drying.

1. *Temperature.*—80 C. in an oven.
2. *Time.*—Not specified.

METHOD A-5

Another Hercules Powder Company method (**239**) described in the 1942 edition of their pamphlet on "Dresinae" follows:

Soil:

Kind.—100 viscosity mid-continent oil.

Application.

1. *Preparation of Panels.*—Thoroughly cleaned.
2. *Method of Application.*—Soiled by squeezing a pile of alternated plates and oil-saturated cloths in a press at 1600 lb. per sq. in. pressure until no more oil is exuded.
3. *Aging Period.*—None.
4. *Deviation.*—Not given.

Cleaning Technique:

Metals.

1. *Kind.*—Steel.
2. *Panel Size.*—2½ by 5½ in.

Solution.

1. *Amount Detergent.*—3 per cent.
2. *Volume Solution.*—1000 ml.
3. *Temperature.*—90 C.
4. *Time.*—Hot bath, 10 min.; electrolytic (anodic or cathodic), 5 min.
5. *Agitation.*—None.
6. *Replicates.*—One.

Method.—Operated as a "soak" bath in one case, or as an electrolytic bath in the other.

Rinsing.

1. *Time.*—Not specified.
2. *Temperature.*—60 C.
3. *Volume.*—Unspecified, from tap.
4. *Agitation.*—Tap water pressure.
5. *Test for Effectiveness.*—None.

Drying.

1. *Temperature.*—80 C.
2. *Time.*—Unspecified.

Measurement of Soil Removal:

Plates photographed under ultraviolet light, which causes any soil remaining on plates to fluoresce and is thus recorded.

METHOD A-6

A soap-silicate specification (**231**) utilizes a cleaning technique described essentially as follows:

Soil:

Kind.—Light mineral oil.

Application.

1. *Preparation of Panels.*—Not specified.
2. *Method.*—Pour 5 ml. of oil over both sides of panel.
3. *Aging Period.*—Allow to drain in vertical position for 5 min.

Cleaning Technique:

Metals.

1. *Kind.*—Aluminum.
2. *Panel Size.*—3 by 6 in.

---

[4] Constant temperature bath, 9 by 4½ by 6½ in., filled with water, equipped with an air stirrer at each end, and a rack for holding four 150-ml. beakers. A Variac is used to control the hot plate used to heat the bath and maintain the temperature constant.

Solution.

1. *Amount Detergent.*—As specified.
2. *Volume Solution.*—Completely immerse panel in properly diluted compound contained in a 2-liter beaker.
3. *Temperature.*—100 C.
4. *Time.*—10 min.
5. *Agitation.*—None.
6. *Replicates.*—One.

Method.—Operated as a "soak" bath.

Rinsing.

1. *Time.*—Not specified.
2. *Temperature.*—Not specified.
3. *Volume.*—Unspecified.
4. *Agitation.*—Dipping.

Drying.

1. *Temperature.*—Room temperature
2. *Time.*—Not specified.

Measurement of Soil Removal:

Method.—Wash dried panel with 100 ml. petroleum ether, carefully collecting ether in a weighed evaporating dish. Evaporate ether on steam bath, then heat evaporating dish in oven at 100 to 105 C. for 15 min. Cool and weigh. Weight from residue must not be more than 1 mg. greater than residue from evaporation of 100 ml. of petroleum ether identical with that used in extraction. The evaporating dish must be cleaned and dried at 100 to 105 C., cooled and weighed to assure correct original weight.

METHOD A-7

Three specifications (221, 225, and 240) have these characteristics:

Soil:

Kind.—S.A.E. No. 50 oil.

Application.—Coat panel with oil in unspecified manner. Aging period, if any, unspecified.

Cleaning Technique:

Metal.

1. *Kind.*—Anodized aluminum alloy.
2. *Panel Size.*—3 by 6 in.

Solution.

1. *Amount Detergent.*—Specified.
2. *Volume.*—Sufficient to permit immersion of plate.
3. *Temperature.*—Unspecified.
4. *Time.*—Time for oil removal is observed.
5. *Agitation.*—None.
6. *Replicates.*—One.

Rinsing and Drying.—Observed in another test.

DISCUSSIONS

The soils used in these tests were mineral oil compositions used in brass rolling, S.A.E. 50 paraffin-base lube oil, 100 (mid-continent) and 200 viscosity mineral oils, light mineral oil, and mineral oil combined with fatty acid, calcium or sodium soap, sulfur-base mineral oil or lanolin.

In general, the removal methods were based on the "soak" tank, although one was operated as an electrolytic bath.

Methods of estimation of degree of soil removal in general were three: (1) the ultraviolet measurement of retention of an oil-soluble fluorescent dye, (2) petroleum ether washing of the cleaned panel for removal of retained oil, and (3) absence of waterbreak.

METHOD B—SOLVENT EMULSION

METHOD B-1

One specification (230) conforms to the outlined method as follows:

Soil:

Kind.—A lubricating oil of S.A.E. 70 viscosity is made into a paste with sufficient talcum powder.

Application.

1. *Preparation of Panels.*—Each panel is cleaned with a suitable solvent.
2. *Method.*—Spread the paste, starting at a distance of 2 in. down from a 3-in. edge over the hollowed side of each panel, until level. Each panel shall be baked in an air oven maintained at a temperature of 290 to 300 F. for 3 hr. Allow to cool to room temperature.
3. *Aging Period.*—Not specified.

Apparently to be used at once.

Cleaning Technique:

Metals.

1. *Kind.*—Aluminum panels cut from corrugated aluminum (the corrugations shall be hollows with about 8 hollows to the inch and the depth of the hollows shall be about $\frac{1}{16}$ in.).
2. *Panel Size.*—3 by 6 in.

Solution.

1. *Amount Detergent.*—25 ml. of compound dissolved in 225 ml. kerosine.
2. *Volume Solution.*—250 ml.
3. *Temperature.*—70 to 90 F.
4. *Time.*—10 min.
5. *Agitation.*—None.
6. *Replicates.*—Apparently only one.

Method.—Suspend the panel with the 6-in. edge in the vertical position in 250 ml. of the prepared liquid. Allow to stand as indicated at the specified temperature. Remove and rinse as indicated.

Rinsing.—Flush each panel with a stream of water (water pressure shall be 30 to 40 lb. per sq. in. gage pressure, and nozzle of hose shall be a glass tube 3 in. long with $\frac{1}{8}$-in. inside diameter). The stream of water must be applied in a horizontal position at right angle to the panel surface and the surface shall be thoroughly flushed.

1. *Time.*—Not controlled.
2. *Temperature.*—Not given.
3. *Volume.*—Not controlled.
4. *Agitation.*—As indicated.
5. *Test for Effectiveness.*—Visual.

Drying.

1. *Temperature.*—Not given.
2. *Time.*—Not given.

Measurement of Soil Removal:

Method.—Visual examination of cleaned section compared with uncleaned portion. The cleaned section should show no more than extremely slight discolorations and no harmful detrimental action.

METHOD B-2

The following data were made available by Lowe of the Pennsylvania Salt Manufacturing Co., Philadelphia, Pa.

Soil:

Kind.

1. Paste of lubricating oil and talcum powder.
2. Dry carbon black of 28 millimicron average particle size (Binney and Smith).
3. Carbon black of B combined with a carbon tetrachloride solution of mineral or lubricating oil and solvent permitted to evaporate.
4. Any drawing or other compound under test.

Application.

1. Soil A is smeared over a corrugated aluminum panel and baked at 300 F. for 3 hr.
2. Ground glass is rubbed with the dry carbon black of soil B.
3. Soil C is smeared on ground glass.
4. Buffing and abrasive compounds are applied to cold-rolled steel panels from a buffing wheel; drawing compounds through action of suitable drawing dies; other compounds by smearing over cold-rolled steel surface with spatula and allowing time to set.

Cleaning Technique:

Metals.

1. *Kind.*—Glass, aluminum, cold-rolled steel, or other metal under consideration.

Solution.

1. *Amount Detergent.*

   10 oz. per gal.—heavy duty cleaning
   5 oz. per gal.—medium cleaning
   $\frac{1}{2}$ oz. per gal.—light cleaning (and power washer application)
   8 oz. per gal.—electrocleaning
   Solvent emulsions: 1 part concentrate to 9 parts kerosine for dip-rinse application; 1 part of kerosine mix to 50 parts water for power washer.
   Steam gun cleaning—$\frac{1}{2}$ oz. per gal.

2. *Volume.*—1 liter for preliminary evaluations. Where results are close, 10 gal. of solution in tank with steam heating coil to produce rolling boil is preferred. For power washer evaluation 40 gal. of solution are required for laboratory scale machine.
3. *Temperature.*—Rolling boil for heavy and medium duty cleaning; 180 F. for aluminum cleaning, power washer application, and electrolytic cleaning.
4. *Time.*—Varies with type of soil under investigation and technique employed; generally 5 min.

5. *Agitation.*—Rolling boil produces sufficient agitation where used. Air agitation is used at lower temperatures.

6. *Current* (electrocleaning), 50 amp. per sq. ft., anodic.

Method.—As indicated above.

Rinsing.

1. *Time.*—30 sec. in spray rinse; 1 min. in beaker or overflow tank rinse.

2. *Temperature.*—Spray rinse is used cold. Overflow tank rinse is cold. Beaker rinses are used at 190 F.

3. *Volume.*—Same volume as cleaner solution—3 successive rinses—for beaker testing. Ten-gallon overflow tank also used for cold rinsing.

4. *Agitation.*—Repeated up and down motion of work.

5. *Test for Effectiveness.*—See test below.

Drying.

1. *Temperature.*—Unspecified.

2. *Time.*—Unspecified

Measurement of Soil Removal:

The soil removal from specimens soiled and applied as in application 2 and apcation 3 is followed by photometric measurement of light transmittance.

The specimen of soil and application 4 is tested by plating the strip from an acid copper bath, under the following conditions:

Copper sulfate	27 oz. per gal.
Sulfuric acid	6.5 oz. per gal.
Temperature	70 to 90 F.
Current density	20 amp. per sq. ft.
Voltage	0.75 to 2.0 v.
Time	1 min.

Rinsing Test:

A 100-ml. sample is prepared at concentration of 4 oz. per gal. Add 0.5 g. ether purified carbon black. Mix for 1 min. in an electric mixer. Immerse a clean microscope slide in the mixture for 30 sec. Remove and place in a beaker of distilled water, permitting the water to rise slightly higher around the slide than when immersed in the cleaning solution. Let remain momentarily, transfer to a second and third beaker of distilled water, employing a similar technique. Allow slide to dry thoroughly, and examine surface for carbon residue. As an alternate method, 0.5 ml. mineral oil may be used together with 0.5 g. carbon black and 100 ml. of the solution to be tested.

METHOD B-3

The following data were developed from very tentative notes made available by Frazer of The Cowles Detergent Co.:

Soil:

Kind.

1. Benzol soot mixed by spatula with 100 viscosity (at 100 F.) straight run mineral oil.

2. One gram L. Martin and Co. Grade J extracted carbon black to 33 drops of 100 viscosity at 100 F. straight run mineral oil, ground together with a spatula.

Application.

1. *Preparation of panels.*—Cleaned by swabbing in trichloroethylene, followed by successive dip rinses in two more beakers of trichloroethylene.

2. *Method.*—Applied as a circular reference spot of about ¾-in. diameter at one end of plate at time of test.

Cleaning Technique:

Metals.

1. *Kind.*—Steel plates.

2. *Size.*—1½ by 6 in.

Solution.

1. *Amount Detergent.*—Unspecified.

2. *Volume.*—About 300 ml. in 400-ml. beaker.

3. *Temperature.*—Room.

4. *Time.*—1 min.

5. *Agitation.*—Soaked in emulsion.

Method.—Soak bath.

Rinsing.

1. *Time.*—About 5 sec.

2. *Temperature.*—About 120 F.

3. *Volume.*—Jet from a ¾-in. hot water tap.

4. *Agitation.*—Spray.

Drying.

1. *Temperature.*—Dried by own heat in air.

Measurement of Soil Removal:

Visual, and by wiping cleaned surface with white cheese cloth.

NOTE—Straight kerosine, a frequent component of cleaners of this type and considered as the reference (since its action alone should be improved by a proper cleaner formulation involving it), did not give complete removal of the carbon spot.

Discussion

The soil used in the evaluation of cleaners for the solvent emulsion method comprised lube oils mixed with talcum powder, carbon black, or benzol soot.

The methods of operation varied somewhat, but generally were of the "soak" tank type.

Considerable care is shown in several methods in designation of the method for rinsing.

Measurement of soil may be visual, visual by comparison with the uncleaned portion, photometric measurement of transmittance through glass, or by electrodeposition of a copper plate to a cleaned steel panel.

METHOD C—ELECTROLYTIC CLEANING

Method C-1

The electrocleaning technique described by Meyer (**241**) follows:

Soil:

Kind.

1. Commercial anhydrous lanolin.
2. Extreme pressure lubricant for heavy and deep drawing operations containing a chlorinated compound.
3. Pigmented drawing compound containing palm oil.

Application.

1. *Preparation of Panels.*
2. *Method.*—These soils were applied under pressure to steel panels and the panels then baked at 350 F. for 20 min.

Cleaning Technique:

Metals.

1. *Kind.*—Steel.

Solution.

1. *Amount Detergent.*—8 oz. per gal.
2. *Temperature.*—200 F.
3. *Time.*—Time recorded for cleaning.

Method.—Anodic or cathodic cleaning at a current density of 10 amp. per sq. ft.

Measurement of Soil Removal:

Absence of waterbreak.

Method C-2

The Hanson-Van Winkler-Munning Co. has developed a laboratory procedure useful for the evaluation of electrolytic metal cleaners.

They describe laboratory apparatus for the evaluation of either soak or electrified cleaners. The equipment provides for positive circulation (by pump) and an overflow bath. A titration method is recommended for determining the effective remaining alkali in the cleaning bath. Use of a laboratory centrifuge (to remove insoluble soil from the used cleaning bath), the control cleaning apparatus, and the titration analyses serve to decide the period at which the bath should be discarded. The apparatus is shown in Fig. 1.

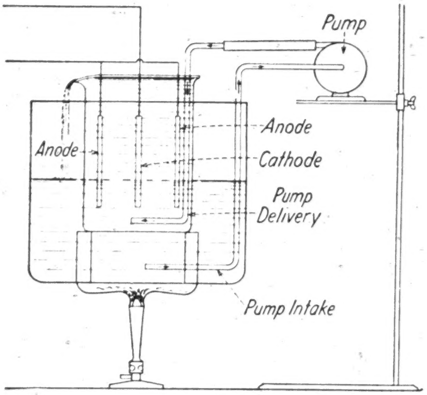

Fig. 1.—Laboratory Apparatus for the Evaluation of Cleaners.

The effects of variation of current density, temperature, and concentration upon the cleaning rate of electric cleaning are illustrated.

Discussion

Relatively few methods for the exclusive evaluation of electrolytic cleaners were found, but a laboratory set-up of interesting potentialities is described and, presumably, a variety of soils may thus be removed.

METHOD D—CARBON REMOVAL

METHOD D-1

The U. S. Naval Engineering Experiment Station (**126**) investigated a tenacious type of soil somewhat similar to that deposited on the surfaces of internal combustion engines. Duralumin panels were soiled by the following method, developed at the station:

1. Heat duralumin to near the softening point,
2. Plunge the specimen into a bath containing 1 per cent of Oildag in N. S. 1100 oil,
3. Burn off oil and bake residue at lower temperature, repeat several times, and
4. Allow the specimen to cool in the bath.

The above method produces a uniform soil which is impervious to ordinary soap and water. The efficiency of several cleansers was determined using this soil.

METHOD D-2

Another suggested soil is that described by Cosgrove (**90**).

A burnt spot of transformer oil was deposited upon a metal surface and measurement and comparison was made of the elapsed time to remove the spot.

METHOD D-3

A cleanser specification (**215**) has the following essentials:

Soil:

Kind.

Asphalt	2.5 per cent
Grade 120 aircraft engine oil	2.5 per cent
Kerosine	20.0 per cent
Xylene	65.0 per cent
Powdered rottenstone	10.0 per cent

Application.

1. *Preparation of Panels.*—Clean sheets well and remove any corrosion or stain by using a mild abrasive such as powdered rottenstone in a suitable liquid vehicle.

2. *Method.*—Coat one surface of each panel placed in a horizontal position with parallel strokes of a soft paint brush, using the previously well shaken soiling mixture. Bake each panel at 143 to 150 C. for 3 hr.

3. *Aging Period.*—Not specified.

Cleaning Technique:

Metal.

1. *Kind.*—Aluminum-coated aluminum alloy.

2. *Panel Size.*—About 2 by 2 in.

Solution.

1. *Amount Detergent.*—10 per cent aqueous solution in soft or softened water. 20 per cent kerosine solution. Prepare similar solutions with the standard sample.

2. *Volume Solution.*—Pour 50 ml. of each of the solutions on separate panels, each to be cleaned with a different solution.

3. *Temperature.*—Room.

4. *Time.*—2 min.

5. *Agitation.*—1 min. with a small stiff bristled brush.

6. *Replicates.*—One.

Method.—Spread the solutions uniformly over the panels with a brush without scrubbing. After 2 min., scrub all of panel with a small stiff bristled brush for 1 min.

Rinsing.

1. *Time.*—Unspecified.
2. *Temperature.*—Cold tap water.
3. *Volume.*—Unspecified.
4. *Agitation.*—Low pressure tap water at 45 deg. angle.

Drying.—Unspecified.

Measurement of Soil Removal:

Examine visually and compare for cleanliness, brightness and residue.

METHOD D-4

The removal of carbon from engine parts (**225, 226**) is effected by the following test:

Soil:

Kind and Method.—Carbonized piston from service engine.

Cleaning Technique:

Metals.

1. *Kind.*—Aluminum alloy.

2. *Size.*—One half or one fourth of piston.

Solution.

1. *Amount Detergent.*—Variable.

2. *Volume.*—Variable.

3. *Temperature.*—135 to 165 F. or other temperature specified.

4. *Time.*—4 hr.
5. *Agitation.*—None.
6. *Replicates.*—One.

Method.—Sections of the same piston are immersed in a solution of standard compound and a solution of test compound.

Rinsing.—In one case (226) no rinsing is given but the piston is wiped at hourly invervals with a cloth, while in the other, water or trichloroethylene and a stiff bristled brush are used.

Drying.—None.

Measurement of Soil Removal:

Visual comparisons between results with test and standard solutions are made for degree of carbon removal.

DISCUSSION

The soil encountered in this type of cleaning is probably more tenacious than others because of method of deposition and attempt to simulate carbon deposition in internal combustion engines. Consequently, some degree of mechanical force may generally be applied to the surface to be cleansed.

The method for evaluation of results is direct comparison with an untreated panel or one which has been cleaned in a composition of known characteristics. Although corrosion induced by the cleaning compositions may be a controlling factor in choice of detergent, this has been considered under the subject of corrosion tests.

METHOD E—FRICTION REMOVAL

The term "friction removal" may be used to cover mechanical, manual, brush, or spray methods for soil removal. This type of soil removal has been segregated from the others simply because of the method used for evaluating the surface cleaners. Although one method described is applied to the removal of soil from a painted panel, the technique involved might readily be applied to soil removal from strictly metallic surfaces.

METHOD E-1

A standard soil and method for removal has been the subject of a Navy Aeronautical specification (242):

Soil:

Kind.—Light mineral oil and Norit A, C, or S.A.U.-30.

Application.

1. *Preparation of Panels.*—Aluminum alloy panels are anodized according to specification, then finished with a specified primer, lacquer and finish coat in scheduled time.
2. *Method.*—Place 1 drop of light mineral oil on prepared panel and spread oil evenly with tip of one finger over this face of the panel. Sift onto the oiled panel face Norit A, C, or S.A.U.-30, using a small cheesecloth bag until the plate is evenly covered. The plate is then turned over and tapped to remove excess carbon.
3. *Aging Period.*—Not specified.

Cleaning Technique:

Metals.

1. *Kind.*—Aluminum alloy panel 0.051 in. anodized according to specification.
2. *Panel Size.*—3 by 6 in. with corners and edges smoothed.

Solution.

1. *Amount Detergent.*—Preparation diluted 1:25.
2. *Volume Solution.*—5 ml.
3. *Temperature.*—Room.

Method.—Pour and spread 5 ml. of 1:25 dilution onto soiled plate. The panel is then flooded with the 1:25 solution and gently brushed with a test tube brush, flushed with 1:25 solution once, rinsed by pouring 500 ml. of water over the panel. All soil and oil should be removed by this process.

Rinsing.

1. *Volume.*—500 ml. of water poured over panel.
2. *Temperature.*—Room.
3. *Agitation.*—None.

Drying.—Not specified.

Measurement of Soil Removal:

Method.—Observe for visual evidence of an oil film, soap film or iridescence. Results shall be equal to or better than those obtained with a standard composition.

METHOD E-2

The evaluation of paint cleaners **(234)** may be made to conform to the outline as follows:

Soil:

Kind.

Metallic brown (Navy Dept. Specification 52B1)	20 g.
Kerosine (Navy Dept. Specification 14K1)	20 g.
Carbon tetrachloride (Navy Dept. Specification 51C34)	20 g.
Heavy white mineral oil (or Nujol) (U.S.P.)	1 g.
Forced feed lubricating oil, Navy Symbol 3120 (WBS 431)	1 g.
Hydrogenated vegetable shortening (Federal Specification EE-L-101)	1 g.

Application.

1. *Preparation of Panels.*—The panels shall be initially prepared by applying in the following order: One coat each of paints conforming to the requirements of Navy Dept. Specifications 52P18, 52P22, and 52P21. A drying time of 2 weeks between coats and a minimum drying time of 1 month after application of the final coat shall be allowed. When tests are to be made, panels prepared as specified above or panels previously used for tests shall be lightly sanded to roughen the paint surface, remove any loose paint, and improve adhesion of the subsequent coat. One coat of paint conforming to the requirements of Navy Dept. Specification 52P21 shall then be applied and allowed to dry for 4 days.

2. *Method.*—The panels which have been dried 4 days are laid flat, and are evenly soiled by brush, using the well-shaken soil given above. The panels are then baked in a horizontal position in a circulating oven at 100 to 105 C. for 30 min.

3. *Aging Period.*—The baked panels shall be used within 24 hr. after soiling.

Cleaning Technique:

Surface.

1. *Kind.*—Steel coated as under application 2.

2. *Panel Size.*—3 by 10 by $^1/_{16}$ in.

Solution.

1. *Amount Detergent.*—50 g. per liter.

2. *Volume Solution.*—87 ml.

3. *Temperature.*—Room.

4. *Time.*—Dependent upon washer apparatus.

5. *Replicates.*—Two.

Method.—Prepare 1 liter each of a trisodium phosphate (U.S.P.) solution and a solution of the compound under test at concentrations of 2 g. per liter in distilled water. Measure the specular gloss of two panels and immerse one panel in each of these solutions, kept at room temperature, for 1 hr. Remove the panels, rinse thoroughly in distilled water, and dry at room temperature. Again measure the specular gloss of each panel. The percentage decrease in gloss of the portion of the panel immersed, compared with the gloss of the same panel before immersion shall be reported for the compound under test and for the trisodium phosphate.

Rinsing.—Rinse well in tap water at room temperature.

Drying.—Dry at room temperature.

Measurement of Soil Removal:

Method.

Reflectometer.—A photoelectric instrument shall be employed for measuring the apparent reflectances of test panels. It shall be calibrated and used in a manner such as to give results as percentage reflectance, relative to magnesium oxide, for conditions of 45-deg. illumination and normal viewing. The instrument shall be of a design such that measurements obtained by its use closely approximate those obtainable through the use of I.C.I. Illuminant C and Standard Observer.

Washability Apparatus.—The apparatus to be used in washing soiled painted panels with a solution of the compound to determine cleaning efficiency shall be equivalent to the apparatus illustrated by Figs. 2 and 3. This apparatus shall consist of a wooden baseboard covered with tinplate, at one edge of which is mounted a heavy duty air-pressure operated windshield wiper. The wiper arm shall extend part way across the base plate and to its end shall be soldered a brass box to serve as a receptacle for a cellulose sponge. The sponge shall be cut to dimensions of $4\frac{1}{4}$ by $1\frac{7}{8}$ by $2\frac{3}{4}$ in. dry, or 5 by 3 by $2\frac{1}{4}$ in. wet. The weight of the box plus dry sponge shall be adjusted to 1 lb., 11 oz., by means of lead washers placed on pins at the corners of the box, and the spring in the wiper arm disconnected to avoid extra pressure. In operation, a soiled painted panel shall be held by stops at the center of stroke of the wiper arm and the number of strokes recorded on an automatic counter. It is not absolutely essential that the sponge box (and sponge) be moved by a windshield wiper as good results can be obtained by moving the sponge box back and forth in the same manner by hand.

Procedure.—Measure the reflectance of a painted panel prepared as specified and soil the panel as specified. Place the soiled panel in the space in the base plate of the washability apparatus and pour over it 50 ml. of a distilled water solution containing 50 g. of compound per liter of solution. Allow the panel to soak 1 min. and in the meantime pour 24 ml. of the same solution over the cellulose sponge and insert this in the box attached to the wiper arm. Start the wiper at the rate of 1 stroke ($\frac{1}{2}$ cycle) per second and allow to continue for 100 strokes (50 cycles). Allow the same detergent solution to drip on the panel from a burette at such a rate that approximately 12 ml. are delivered during the 100-stroke period. Remove the panel and sponge, rinse the panel, and squeeze out the sponge in cold tap water. Replace the panel in the space provided for it, but reversed end for end from its previous position. Repeat all the previous cleaning steps but omit the addition of 50 ml. of solution to the panel. Remove the panel, rinse well with tap water, and dry at room temperature. Again measure the reflectance of the panel. Make duplicate determinations of the cleaning efficiency at 50 g. per liter concentration in distilled water and duplicate determinations in synthetic sea water.

Measure reflectance of the painted panel prior to soiling, then repeat the reflectance measurement after the washing process.

Calculate cleaning efficiency by the following formula:

$$\text{Per cent Cleaning Efficiency} = \frac{R_2}{R_1} \times 100$$

where

R_1 = Reflectance of unsoiled, unwashed painted panel, and

R_2 = Reflectance of soiled, washed painted panel.

METHOD F—PAINT STRIPPING

Although paint stripping may not usually be considered as metal cleaning, the fact that there is a demand for such products, secured under specification, is indication that there is a demand for materials to produce this effect. The technique used in evaluation of such products falls into the metal cleaning category.

METHOD F-1

Several specifications **(220, 221, 223, 240)** have been developed for the evaluation of paint strippers. Their essential characteristics have been condensed to the standard form.

Soil:

Kind.—Primer of zinc chromate and two enamel coats of varnish, cellulose nitrate or high resin phthalate lacquer, glyceryl phthalate enamel, or black glyceryl phthalate.

Application.

1. *Preparation of Panels.*—Anodized
2. *Method.*—Primer is sprayed onto one side and dried 1 hr. before next coat. Varnish, enamel or lacquer is then applied according to schedule with definite time periods between coats and before baking, as well as definite baking periods and temperatures.
3. *Aging Period.*—Not specified. Apparently used at once.

Cleaning Technique:

Metals.

1. *Kind.*—Aluminum-alloy sheet coveredwith chromic-acid type anodic film.
2. *Panel Size.*—3 by 6 in. by 0.051 in. properly numbered.

Solution.

1. *Amount Detergent.*—Not given.
2. *Volume.*—Complete immersion or brushed onto surface being stripped.
3. *Temperature.*—Room, or specified.
4. *Time.*—If brushed on, 5-min. intervals between applications, or if immersed, the time for removal is observed by stroking with a soft bristle brush.
5. *Agitation.*—As indicated under "Time."
6. *Replicates.*—Apparently one.

Method.—Solution 2 and solution 4.

Rinsing.

1. *Water.*
   - (*a*) *Time.*—Indefinite to 5 min.
   - (*b*) *Temperature.*—77 to 185 F.
   - (*c*) *Volume.*—Unspecified.

  (d) *Agitation.*—Unspecified.
2. *Trichloroethylene.*
  (a) *Time.*—Few seconds.
  (b) *Temperature.*—Room.
  (c) *Volume.*—Unspecified.
  (d) *Agitation.*—Unspecified.
  (e) *Drying.*—Room temperature.

Measurement of Soil Removal:

Method.—Visual, for corrosive attack, oxidation, discoloration, and presence of stripping solution.

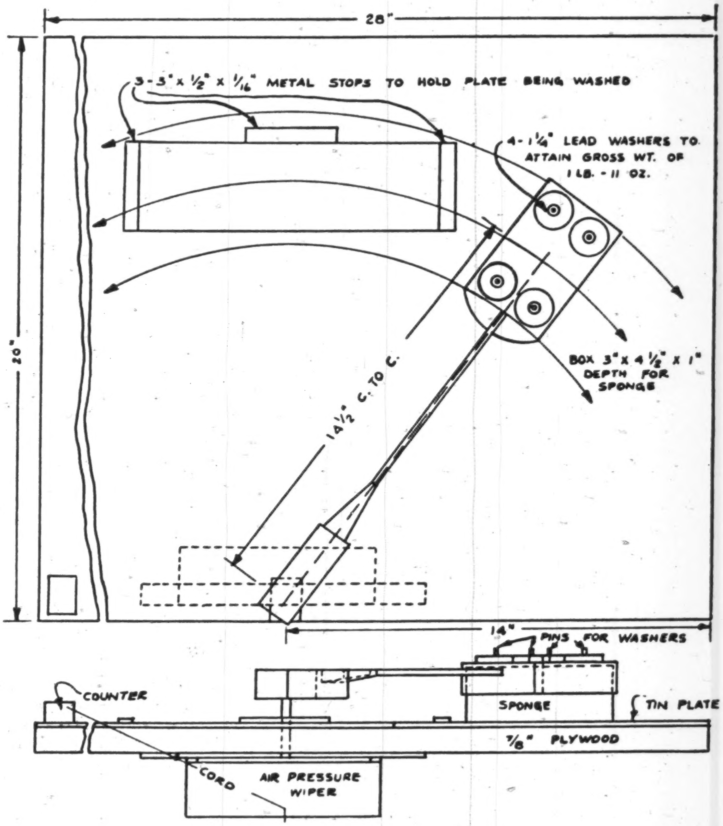
28"
3-3" x ½" x 1/16" METAL STOPS TO HOLD PLATE BEING WASHED
4-1¼" LEAD WASHERS TO ATTAIN GROSS WT. OF 1 LB. - 11 OZ.
20"
14½" C. TO C.
BOX 3" x 4½" x 1" DEPTH FOR SPONGE
14"
PINS FOR WASHERS
COUNTER
SPONGE
TIN PLATE
7/8" PLYWOOD
CORD
AIR PRESSURE WIPER

FIG. 2.—Washability Apparatus.

DISCUSSION OF SOIL

It is evident from the variety of soils described, and their method of preparation, that a single soil will not cover all the possible conditions encountered, nor is this necessary. A lightly adherent soil will yield to less drastic treatment than tenacious soils, and the composition of the basis metal will influence the choice of both cleansing agents and methods of operation.

A number of investigators have carefully considered the method of soil application but not all have reported upon the reproducibility of their soils. It is presumed that the panels are free from contaminants prior to application of the soil, or that this has no bearing upon results, but several methods rightly contain definite directions in this respect.

In the interest of improved reproducibility, definite directions should be given for the preparation of the panel prior to soil application, even though this may seem superfluous. Specific, clear directions should be given for the preparation and application of the soil to the panel surface, and pertinent variables should be under full control. The age of the soil may have marked bearing upon ease of removal, and several methods contain a specification to control this factor, so that directions should be given to avert possibility of error from this source.

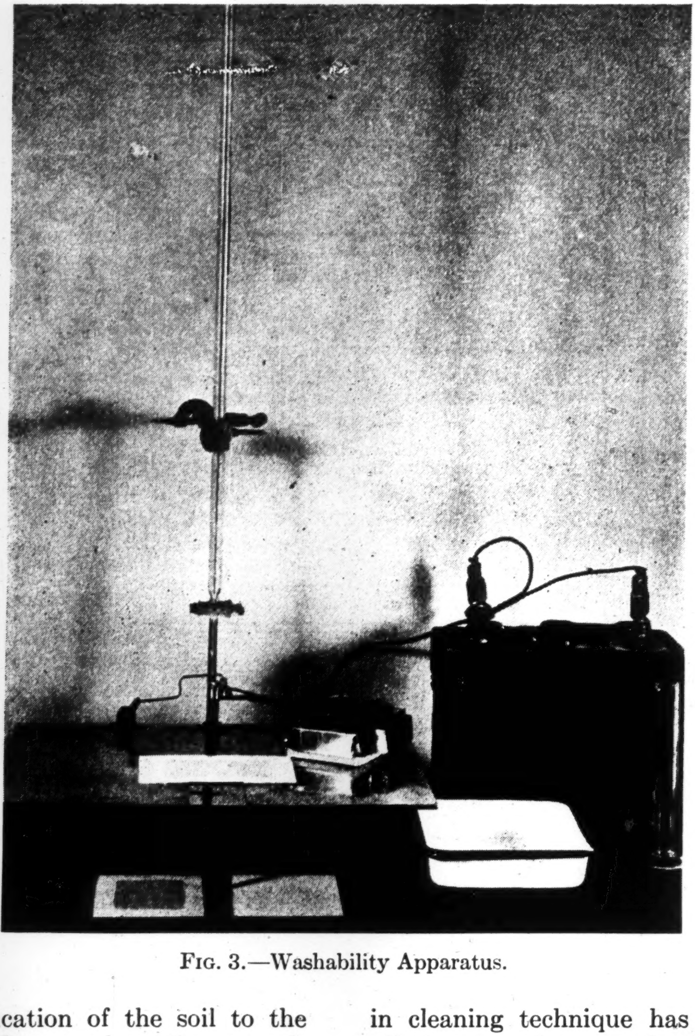

FIG. 3.—Washability Apparatus.

DISCUSSION OF CLEANING TECHNIQUE

Control of the factors involved in cleaning technique has marked effect upon the reproducibility of the method. Presumably, the cleaning method (soak tank, etc.) is conducted either under arbitrary conditions or ones which attempt to reproduce plant conditions.

Few of the tests indicated the number of replicate tests which were necessary to substantiate findings, perhaps because of insensitiveness of the means for measuring the degree of soil removal.

The ease of removal of cleaning composition contaminated by soil is an important factor and several tests for rinsing effectiveness have been developed. It is obvious that a detergent must not only assist in removing soil from a given surface, but must retain the soil in suspension so that the surface is not recontaminated upon withdrawal from the cleaner bath, or upon rinsing.

DISCUSSION OF MEASUREMENT OF SOIL REMOVAL

One of the most difficult features of the actual cleaning test is determination of degree of effectiveness of soil removal. The test most often used, under the theory that a clean surface will be uniformly wetted by water, is the time-honored "waterbreak" method. The absence of "waterbreak" is taken as indication of absence of oily, water-repellent contaminant. Recently developed information indicates that preferential adsorption can take place at metal or other surfaces, and that this could take place with metals presenting a presumably "clean" surface because the adsorbed coating is "hydrophilic" or the opposite of water-repellent. The presence of such a film, however, might not be desirable at a subsequent step in the manufacturing operation. Consequently, a more specific and sensitive test is desirable.

One of the most recent advances in measurement of soil retention is that of Morgan and Lankler who utilized a fluorescent dye, ultraviolet light, and photography. The sensitivity of the method was checked gravimetrically and the minimum amount of oil detectable (containing the fluorescent dye) was 0.000004 g. per sq. cm. of metal surface. The application of photometric measurement to this technique would provide more rapid and valuable data.

Photometric means for measurement of reflectance are used in one method in which partial or total removal of soil is effected. The advantage to photometric measurements is obvious since comparisons automatically become numerical.

SUMMARY

None of the methods described is recommended by Section G, since the object of this paper is to present all available methods and to evaluate them according to an "ideal" outline. It is expected that the data thus developed will aid materially in subsequent Section work.

The varieties of soils which may potentially contaminate metal are many, and the possible methods which may be utilized in removal of such soils are likewise varied. It is not unusual, therefore, that published methods for laboratory evaluation of soil removal are numerous and that techniques are also varied.

No attempt is made either to dictate which soil shall be used, nor the method of removal, but factors which may be variable should be recorded and greater attention paid to attempts to improve the degree of reproducibility. To this end, a general outline is given covering the preparation and application of the soil, the cleaning technique, and the measurement of degree of soil removal. Only recently have efforts been made to utilize other than visual or gravimetric methods for estimation of degree of soil removal, both of which are lacking in sensitivity. Recently developed methods use either photometric measurement of soil removal or photographic measurement of fluorescence produced by dye present in oil which contaminates a metal surface.

Evaluation of seventeen methods for measurement of soil removal indicates the need for closer control of all factors involved in the evaluation method. This will be particularly true with the development of more accurate and sensitive methods which can be used for evaluation of the cleaned surface.

Acknowledgment:

The suggestions made by Section G members R. B. Mears, Aluminum Corporation of America, and William Stericker, Philadelphia Quartz Co., have been of material assistance to me in the preparation of this paper.

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THE DETERMINATION OF THE TERPENE ALCOHOL CONTENT OF STEAM-DISTILLED PINE OIL[1] *

By V. E. Grotlisch[2] and H. N. Burstein[3]

Steam-distilled pine oil is a mixture of terpenes obtained from the heartwood of old longleaf yellow pine stumps by a steam and solvent recovery process. It consists essentially of tertiary terpene alcohols (chiefly alpha-terpineol), and the secondary alcohols borneol and fenchyl alcohol, together with relatively smaller quantities of terpene hydrocarbons, such as alpha- and beta-pinene and dipentene, and the terpene ethers cineol, methyl chavicole, and anethole.

The principal uses of pine oil are as a frothing agent in the flotation process of ore recovery in the mining industry, as a penetrant and a wetting agent in the scouring of wool, and as a thinner and setting retardant in some types of paint and varnish. Pine oil is also used in the manufacture of insecticides, disinfectants, cattle dips and sprays, as a perfume or counter-odorant in cleaning compounds, and as a source of certain chemicals and pharmaceuticals—terpene alcohols and their derivatives and terpin hydrate.

The commercial value of pine oil, for most of these uses, is dependent primarily upon its terpene alcohol content, and to a lesser extent, upon the absence of moisture. The high-gravity, light-colored commercial pine oils contain the highest percentage of alcohols and are almost anhydrous. In spite of the importance of the alcohol content of pine oil, methods used in the industry for determination of terpene alcohols when this study was begun in December, 1942, had not been completely standardized.

Correspondence with several pine oil producers regarding their methods of test brought forth opinions that the methods were not entirely satisfactory but were the best available. This study was undertaken to explore the possibilities of standardizing existing methods as well as of developing new methods of determining the alcohol content of pine oil.

Evaluation of Selective Terpineol Dehydration

Some of the methods studied during the initial stages of this work were concerned with the determination of only the terpineol content of pine oil and were based on the supposition that only this constituent breaks down to water and dipentene when the pine oil is boiled with a weak catalyst in the presence of sufficient mineral oil to keep the temperature down. Although this principle could be applied to industrial separations,[4] its quantitative application was open to question.

One procedure called for a certain amount of refluxing with phthalic anhydride, to protect the secondary alcohols by esterification, before proceeding with the dehydration of the terpineol.

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[3] Chemist, Naval Stores Section, Cotton and Fiber Branch, Office of Marketing Services, War Food Administration, Washington, D. C.

[4] "Method of Separating Certain Components from Pine Oil," U. S. Patent No. 1,932,183, October 24, 1933.

Our experiments showed that only a partial esterification takes place in any reasonable length of time. According to the work of Chadwick and Palkin (**1**),[5] it was necessary to reflux fenchyl alcohol and phthalic anhydride in benzene solution for 48 hr. in order to prepare the acid phthalate in substantially quantitative amount. This, of course, is entirely impractical for an analytical procedure.

By increasing the quantity of mineral oil present, an attempt was made to find a minimum temperature at which terpineol would be dehydrated without affecting the secondary alcohols. This was also unsuccessful, as the temperature at which complete dehydration of terpineol occurred was also high enough to cause decomposition of some of the secondary alcohols.

Experimental Procedure for Selective Terpineol Dehydration.—Samples of the tertiary and secondary alcohols, and known mixtures containing alpha-pinene to simulate various types of pine oil, were selected for study.

A 100-g. portion of each sample, to which had been added an equal quantity of mineral spirits (Varsol), was dehydrated by using weak catalysts of the type recommended for selective tertiary alcohol dehydration. These included fuller's earth, metallic copper and a trace of iodine, and solid potassium acid sulfate.

Some runs were made with a preliminary refluxing with phthalic anhydride. Additional runs were made in which the volume of mineral oil present was increased to permit the dehydration to take place at lower temperatures.

The water liberated was collected in a Barrett-type moisture trap, and the terpineol content of the mixture calculated and compared with the amount of terpineol known to be present.

The results presented in Table I show conclusively that terpineol is not completely dehydrated in all cases by these catalysts, with time and temperature both affecting the results to a large degree. On the other hand, borneol and fenchyl alcohol are also substantially dehydrated (up to 77 per cent) by fuller's earth alone. Hence, the above type of procedure cannot be used to measure the terpineol content of pine oil quantitatively.

TABLE I.—PERCENTAGE DEHYDRATION OF TERPENE ALCOHOLS, USING WEAK CATALYSTS.

Alcohols Present, per cent		Alpha Pinene, per cent	Catalyst or Method Used	Indicated Percentage of Tertiary Alcohols
Tertiary	Secondary			
100	...	..	Copper and I_2, 8 hr. at 171 C.	Variable, up to 100
100	...	..	Solid $KHSO_4$, 5 hr. at 176 C.	100
100	...	..	Copper and I_2, 4 hr. at 147 C.[a]	30
100	...	..	Solid $KHSO_4$, 4 hr. at 116 C.[a]	30
100	...	..	Fuller's earth (numerous runs)	Variable, all less than 100
25	...	75	Fuller's earth (one run)	13
...	100	..	Copper and I_2	58
...	100	..	Fuller's earth	77
...	100	..	Phthalic anhydride, fuller's earth	43
42	19	39	Fuller's earth	60
60	20	20	Phthalic anhydride, fuller's earth	67 to 70
60	20	20	Copper and I_2	53 to 63

[a] Reflux temperature decreased by addition of excess quantity of mineral oil.

Selective halogen addition to the terpene alcohols was also tried and discarded, since quantitative halogen addition to terpene alcohol mixtures was impossible to control, due to substitution on all the alcohols.[6] Other investigators have come to the same conclusion concerning halogen addition as a means of measuring unsaturation in the terpene series (2).

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[5] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1022.

[6] Wijs iodine procedure, Klimont bromine method (*Arch. Pharm.*, Vol. 250, p. 579 (1912)), and thiocyanogen addition were all tried and found unsuccessful. For a further study, see Joshel, Hall, and Palkin, *Ind. Eng. Chem.*, Analytical Edition, Vol. 13, p. 447, July 15, 1941.

Although there is evidence to indicate that the terpineol content of pine oil could be determined by catalytic hydrogenation after removal of all terpene hydrocarbons, as in the borate method described later in this paper, this was not attempted, as it was felt that such an involved method, using special equipment of high initial cost and requiring considerable skill in its manipulation, was not suitable for a standardized analytical procedure.

TOTAL TERPENE ALCOHOL DEHYDRATION

It was decided that a method of estimating the total alcohol content of pine oil, rather than the terpineol content alone, would best serve as a means for evaluating the product, until such time as a satisfactory procedure for terpineol assay could be developed. Ono, Hirayama, and Matsuzaki (3) had shown that the various terpene alcohols could be quantitatively dehydrated by using phosphoric acid as the catalyst. As variations of this procedure were evidently being used in several commercial laboratories, it was considered desirable to study and attempt to standardize it.

In this connection it is to be noted that this is not a simple dehydration to dipentene and water, as it has been shown (4) that when terpineol is dehydrated the resulting end product consists of a mixture of dipentene, terpinene, terpinolene, and lower boiling menthadienes, as well as unidentified high boiling products, probably terpene polymers.

In order to test the effectiveness of a proposed method, using small quantities of both fuller's earth and phosphoric acid at the same time, on the terpene alcohols found in American pine oil, the dehydration was carried out on several samples of alcohols as follows:

Experimental Procedure for Catalytic Dehydration.—A 0.1-g. portion of fuller's earth was weighed into a tared, 250-ml. round-bottom flask containing a few glass beads. A 100-g. portion of a known solution of the alcohols in pinene was pipetted into the flask along with 0.3 ml. of syrupy phosphoric acid. The flask was connected to a Barrett-type water trap[7] fitted at the top with a reflux condenser, and at the bottom with a rubber tube and movable mercury reservoir.

After bringing the mercury level up into the graduated leg of the trap to $\frac{1}{2}$ in. below the side tube, gentle heat was applied until the reaction started. The reaction proceeds vigorously at first with very little heating. The water and hydrocarbons formed were collected in the trap, the mercury level being lowered, when necessary, to retain the water. When the reaction appeared to have slowed down, as indicated by a slow increase in the volume of water collected, most of the hydrocarbons were returned to the flask by raising the level of the mercury in the trap. Then the mercury level was again lowered to permit continued distillation and trapping of the distillate. After several such operations, and when it was evident that no more water was being liberated,

TABLE II.—PERCENTAGE DEHYDRATION OF TERPENE ALCOHOLS, USING FULLER'S EARTH AND PHOSPHORIC ACID CATALYSTS.

Alcohol	Calculated Percentage of Alcohols
Terpineol liquid (practical grade).	104.3, 104.1, 105.0[a]
Terpineol (recrystallized, melting point 37 to 39 C.)	100.3, 99.5, 101.1, 98.4, 99.2, 100.6, 99.4, mean 99.8
Fenchyl alcohol (technical)	100.2, 97.5
Borneol (pure)	99.1, 99.4

[a] High results probably due to dissolved moisture.

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[7] Later, a specially designed, more accurate and more suitable water trap was provided for this method. Its design is shown in Fig. 1 of the A.S.T.M. Tentative Methods of Sampling and Testing Pine Oil (D 802 - 44 T), 1944 Book of A.S.T.M. Standards, Part II, p. 1520, and Part III, p. 2086.

the distillation was stopped. Each milliliter of water collected in the trap represents 8.56 g. of terpene alcohol having a molecular weight of 154.14. The results are shown in Table II.

From these results it could be concluded that this method should prove satisfactory for determining the total alcohols in pine oil, but it seemed desirable to obtain further proof that such a conclusion was justified. (Cineole would also be dehydrated along with the alcohols, thereby tending to give high results, but since the cineole content of pine oil is quite small, it was felt that this would not have a material effect on the results obtained by this method.)

APPLICATION OF OTHER METHODS OF ALCOHOL DETERMINATION

As an entirely different approach to the problem, consideration was given to other possible methods based on conversion of the alcohols to esters or to compounds other than water. Here three procedures seemed to possess possibilities, namely, acetylation, the Zerewitinoff method (5), and the Kaufmann borate procedure (6).

Acetylation:

Although the terpene alcohols borneol and menthol react quantitatively with acetic anhydride to form acetates, the reaction in the case of tertiary alcohols does not proceed to completion, due mainly to the opposing reactions of hydrolysis and dehydration. Chemists in the laboratory of Schimmel and Co. (7) found that after 45 min. only 84.4 per cent of linalool had been esterified, and after 120 min. there was only 77.9 per cent of ester left in the reaction mixture. From this it was assumed that decomposition of both ester and alcohol begins before acetylation is complete. A. Verley and F. Bölsung (8) tried to acetylate terpineol quantitatively in pyridine solution, but this variation of the procedure also failed due to decomposition as above. In the face of such evidence, acetylation was disregarded as a means of determining the alcohol content of pine oil. It has not yet been possible to explore the possibilities in the analysis of pine oil of several more recent modifications of the esterification procedure, including a formulation process in special solvents. It is hoped that this can be done in the near future.

The Zerewitinoff Method:

The Zerewitinoff method determines the active hydrogen content of a material and is therefore adapted to the alcohols. Its further study was suggested by Zerewitinoff's recorded successful results with the terpene alcohols themselves (9). The method depends essentially on the reaction between the alcohols and methyl magnesium iodide (Grignard reagent), with the evolution of methane, the volume of which serves as a basis for the calculation of the alcohol content. The authors successfully repeated Zerewitinoff's results, as shown by the data in Table III. No immediate explanation can be advanced for the slightly low values obtained by us for borneol, but they are not considered

TABLE III.—PERCENTAGE OF ALCOHOLS FOUND IN TERPENE HYDROCARBONS AND ALCOHOLS BY ZEREWITINOFF METHOD.

Sample	Alcohols Found, per cent
Alpha-pinene	0
Beta-pinene	0
Dipentene	0
Anethole	0
Terpineol[a]	99.4, 100.7
Borneol[b]	93.3, 94.0
Fenchyl alcohol[c]	97.7, 98.9
49 per cent total alcohols, 51 per cent other terpenes[d]	48.4, 50.6
68 per cent total alcohols, 32 per cent other terpenes[d]	68.0, 68.2

[a] Recrystallized from EK terpineol.

[b] E. & A. pure borneol.

[c] Technical grade, supplied by Givaudan-Delawanna Inc., New York, N. Y.

[d] Mixtures of terpineol, borneol, and fenchyl alcohol with pinene and dipentene, prepared as percentages by weight.

to be of particular concern, in view of the relatively small percentages of this secondary alcohol in natural pine oils. Particularly gratifying were the findings that the terpene hydrocarbons and ethers would not interfere with the action of the Grignard reagent. Zerewitinoff had previously stated that fenchone, camphor, and menthone also did not interfere.

A series of tests were then run on three authentic samples of steam-distilled pine oil, all of which had previously been tested by the dehydration method. The procedure outlined below was followed. Results are tabulated in Table IV.

TABLE IV.—ANALYSIS OF PINE OILS FOR TOTAL ALCOHOL CONTENT BY ZEREWITINOFF METHOD FOR ACTIVE HYDROGEN.

Pine Oil A 81.5; 81.3; 81.5; 81.0; average 81.3 per cent by dehydration					Pine Oil B 78.5 per cent by dehydration					Pine Oil C 73.1 per cent by dehydration				
Weight of Sample, g.	Volume of Methane (corrected), ml.	Alcohols Found, per cent	Deviation from Mean, per cent	Deviation from Dehydration Value, per cent	Weight of Sample, g.	Volume of Methane (corrected), ml.	Alcohols Found, per cent	Deviation from Mean, per cent	Deviation from Dehydration Value, per cent	Weight of Sample, g.	Volume of Methane (corrected), ml.	Alcohols Found, per cent	Deviation from Mean, per cent	Deviation from Dehydration Value, per cent
0.1889	21.8	79.9	0.1	1.4	0.3039	33.4	76.1	1.0	2.4	0.2104	20.8	68.3	1.7	4.8
0.1997	22.5	78.1	1.9	3.2	0.1862	20.7	77.1	0	1.4	0.2062	21.5	72.1	2.1	1.0
0.2794	32.2	79.8	0.2	1.5	0.2838	32.3	78.9	1.8	0.4	0.2791	29.0	72.0	2.0	1.1
0.1951	22.7	80.5	0.5	0.8	0.2051	22.6	76.6	0.5	1.9	0.2090	20.7	68.5	1.5	4.6
0.2470	28.9	80.9	0.9	0.4	0.1902	21.1	76.6	0.5	1.9	0.2287	23.3	70.3	0.3	3.2
0.2665	31.1	80.8	0.8	0.5	0.1774	19.5	75.9	1.2	2.6	0.2538	26.2	71.4	1.4	1.7
					0.2572	28.8	77.5	0.4	1.0	0.2132	21.2	68.7	1.3	4.4
					0.2630	29.2	76.8	0.3	1.7	0.2558	25.5	70.0	0	3.1
					0.2529	28.8	78.8	1.7	0.3	0.2446	24.4	69.1	0.9	4.0
Mean		80.0	0.75	1.3	....	..	77.1	0.8	1.5	....	....	70.0	1.25	3.1
Maximum Deviation		..	1.9	3.2	....	..	..	1.8	2.6	....	..	..	2.1	4.8

Experimental Procedure for Zerewitinoff Method.—A 0.17 to 0.30-g. sample was accurately weighed out into the large compartment of a special Zerewitinoff tube, and dissolved in 15 ml. of dry xylene. Five milliliters of Grignard reagent in dry diisoamyl ether (or in dry phenetole) were then pipetted into the small arm of the reaction tube, and the tube connected to a water-jacketed gas burette of the Lunge type, containing mercury and fitted with a leveling tube.

The stopcock of the burette was removed for a moment to equalize the gas pressures, and then, with the stopcock opened to the atmosphere, the leveling tube was raised until the burette was filled with mercury. The stopcock was then closed.

The solutions in both arms of the reaction tube were then brought together, and at the same time the gas burette was opened to the reaction tube. The evolved methane was kept at atmospheric pressure by lowering the leveling tube. The reaction tube was shaken vigorously for several minutes until no more methane was evolved. The system was allowed to come to equilibrium, and the volume of methane read. The percentage of alcohols in the sample was computed as follows:

Alcohols, per cent

$$= \frac{V_0 \times 0.000719 \times 154.14 \times 100}{16W} - 8.56M$$

where:

V_0 = volume of methane corrected to 0 C. and 760 mm. pressure and corrected for the vapor pressure of xylene,

154.14 = molecular weight of the alcohols sought,
W = weight of sample taken,
0.000719 = weight of 1 ml. of methane at standard conditions,
16 = molecular weight of methane, and
M = percentage of moisture in sample.

The values obtained were in most cases slightly lower than those obtained by the dehydration method. It must be remembered that the latter tends to give slightly high results, whereas the Grignard reagent method gave slightly low results with the secondary alcohols. If the values in Table IV showing a deviation from the dehydration method of more than 2 per cent on sample B, and more than 4 per cent on sample C, were eliminated from the calculations, then the mean values for total alcohols become 77.5 and 71.2 per cent, respectively, which are less than 1 per cent off from the dehydration values. We believe that it is safe to conclude that the Zerewitinoff method can be used for determining the total alcohol content of pine oil within a maximum probable error of ±3 per cent.

The method seems especially adaptable to the plant control laboratory because of the speed with which individual samples can be tested, as well as to the central testing laboratory where frequently only small quantities of sample are available. It is hoped that further study may result in eliminating some factors, not now evident, which caused the wide variations recorded.

The Kaufmann Borate Procedure:

A. A. Kaufmann (6) showed that higher alcohols can be separated from other constituents of a mixture by the use of ethyl borate. This method involves five steps: (*a*) the conversion of the alcohols to their nonvolatile borates, (*b*) removal of the nonalcoholic constituents from the reaction mixture, (*c*) hydrolysis and regeneration of the terpene alcohols, (*d*) extraction, washing, and drying of the extracts, and (*e*) removal of the solvent and weighing the recovered terpene alcohols. Chadwick and Palkin (1) used this method, but with butyl borate instead of ethyl borate, in their examination of steam-distilled wood turpentine. For use with pine oil, several modifications of their procedure were found necessary.

Several different mixtures containing known amounts of terpene alcohols were first analyzed, followed by two samples of steam-distilled pine oil which had previously been tested by dehydration. The procedure outlined below was followed:

Experimental Procedure for Borate Method.—Fifty grams of sample, 40 g. of *n*-butyl borate (10) and 20 g. of xylene were heated with constant stirring at 70 C. for 30 min. at 60 mm. pressure, using an oil bath. The temperature of the bath was raised and the pressure lowered to distill off the solvent, excess reagent, butyl alcohol, and nonalcoholic portions of the sample. The distillation was continued for some time at 4-mm. pressure and at a bath temperature of 125 C., and finally stopped when no more distillate came over.

The residue of mixed terpene alcohol borates was then transferred to a separatory funnel and hydrolyzed, merely by shaking with 200 ml. of 5 per cent NaOH solution, and the liberated alcohols were extracted with several portions of petroleum ether. The combined ether extracts were washed until free of butyl alcohol, and subsequently dried over anhydrous sodium carbonate. Finally the solvent was removed by evaporation under reduced pressure. The isolated alcohols were weighed.

It was at first thought that the method

could be shortened by weighing the terpene alcohol borates obtained after the first vacuum distillation of the reaction mixtures, and computing the percentage of alcohols from this value. After many experiments it was concluded that this was not possible, as the results were not uniform. Whether an explanation of this lies in the fact that the borate esters formed did not always possess the same structures is not certain, but the results pointed in that direction. It is possible that the reactions proceeded in such a way as to cause varying relative amounts of boric acid esters to be formed, wherein one, two, or possibly three terpinyl groups replaced the *n*-butyl groups on the boron atom. When the same idea is carried further and applied to the secondary alcohols, the number of mixed terpinyl-fenchyl-butyl borates possible is evident, and it can readily be realized why any idea of using a gravimetric factor in connection with the weight of the borate residues had to be abandoned in favor of the longer hydrolysis procedure.

TABLE V.—PERCENTAGE RECOVERY OF ALCOHOLS BY BORATE METHOD.

Alcohols Present in Known Mixture, per cent	Alcohols Found, per cent
75.6[a]	75.6
100.0[a], several mixtures	97.5, 100.0, 99.1, 99.2, 98.0, 99.2, 100.0, average recovery 99.0
0.0[b]	0.0
74.0[c], by dehydration	73.2
78.5[d], by dehydration	77.0

[a] Synthetic mixtures of terpene alcohols and hydrocarbons made up by weight.

[b] A mixture of alpha pinene and dipentene from commercial sources.

[c] Regular steam-distilled pine oil.

[d] Steam-distilled pine oil, same as sample B in Table IV.

Results obtained by the above procedure on the pure alcohols and mixtures thereof were very close to the theoretical, as shown in Table V. In the case of the two steam-distilled pine oils, results averaged about 1 per cent lower than the results obtained by dehydration. However, as previously pointed out, dehydration results may sometimes be slightly high, while on the other hand, there is a possibility of a slight loss of material in the borate method due to handling through the various steps, and to volatilization of traces of terpene alcohols under vacuum.

An important advantage of the borate procedure lies in its applicability to all pine oils regardless of interfering substances. The presence of any dihydroxy alcohols or terpin hydrate in a pine oil would result in excessive values for alcohol content where the dehydration or the Zerewitinoff procedures are employed, since each mole of polyhydroxy alcohol contains two or three moles of measurable hydroxyl. Using the borate procedure such error would be avoided, as only the actual weight of the terpene alcohols is involved. Although ordinary terpin hydrate, the hydrate of 1,8-terpin, occurs to only a slight extent in fresh essential oils, it may be formed in many of them on long standing (11). In the case of synthetic pine oils, there is reason to believe that small amounts of terpin and terpin hydrate are present, since such pine oil can be made from pinene through a terpin hydrate process, with a yield up to about 89 per cent of terpineol (12). One synthetic pine oil tested in this laboratory showed an alcohol content, as determined by dehydration, 12 per cent higher than the results obtained by the borate method. The moisture present in the sample as subsequently determined accounted for 6 per cent of the difference leaving an additional 6 per cent unaccounted for, which may have been due to the presence of a small amount of unconverted polyhydroxy terpene compounds.

Dissolved moisture is also a serious interfering factor where dehydration or the Grignard reagent is employed and must be determined by some reliable procedure and deducted from the alcohol figure. Water content does not affect the Kaufmann procedure. Finally, of course, the Kaufmann method offers a means of isolating the alcohols of a pine oil for further study, processing or identification.

CONCLUSIONS

The determination of tertiary and secondary alcohols in pine oils cannot be made with any degree of accuracy by any of the selective dehydration procedures so far proposed. The amount of tertiary alcohols could not be determined by measurement of the amount of unsaturation.

The total terpene alcohol content of pine oil can be determined by dehydration with fuller's earth and phosphoric acid. The Zerewitinoff procedure for active hydrogen is also suitable for determining total alcohols in steam-distilled pine oils since it gives results in fairly good agreement with the dehydration method within a limit of error not out of keeping with the recognized and accepted deviations for many other test methods applied to naval stores products.

The Kaufmann borate procedure may be used to check the results obtained by either of the above methods, and also provides a method by which the combined alcohols may be recovered from a pine oil, if desired for further study.

In the first and second procedures mentioned, the amount of moisture present as such in a pine oil must be taken into account, since each percentage of such dissolved moisture, if not allowed for, would erroneously increase the computed percentage of terpene alcohols by 8.56 per cent. A further study of methods for determining the moisture content of pine oil, as well as of drying samples preparatory to analysis, is being made.

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SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON ADHESIVES

The Symposium on Adhesives, sponsored by A.S.T.M. Committee D-14 on Adhesives and presented in conjunction with technical committee meetings of A.S.T.M. Committees D-9 on Electrical Insulating Materials and D-20 on Plastics, was held on Wednesday, October 10, 1945, at the Hotel Claridge in Atlantic City. Mr. Eugene O'Hare, Casein Company of America, was Chairman of the Symposium Committee.

The purpose of this symposium was to provide an opportunity for discussing the properties of adhesives and the possibilities and means of standardization in the adhesives field. The symposium was intended to emphasize the use of adhesives as an engineering tool in the assembling of materials by adhesion, and also served to orient the work of Committee D-14.

Seven papers were presented, five of them prepared by the various subcommittee officers from information supplied to them by their members, who are technical authorities representing leading consumers and producers. Thus the papers represent a composite of the knowledge and ideas of the committee members.

The seven papers, presented at a morning and afternoon session, were as follows:

Types and Uses of Adhesives—T. R. Truax and R. F. Blomquist
A General Theory of Adhesion—R. C. Rinker and G. M. Kline
Strength Properties (Subcommittee I)—R. C. Platow and A. G. H. Dietz
Analytical Procedures Used on Adhesives (Subcommittee II)—Leonard Repsher
Permanence Tests of Adhesive Bonds (Subcommittee III)—Fred Wehmer
Adhesive Working Qualities (Subcommittee IV)—C. B. Hemming
Preparation and Use of Specifications for Adhesives (Subcommittee V)—Gerald Reinsmith

Mr. O'Hare acted as technical chairman at each of the sessions.

The papers have been issued by the Society as a separate publication entitled "Symposium on Adhesives."

SUBJECT INDEX

VOLUME 45

A

Absorption Tests.

A Comparison of Absorption and Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 771.

Accelerated Testing.

See **Corrosion; Weathering.**

Acidity.

Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Additions.

Effect of Heat on Portland Cements Containing Vinsol Resin—Leonard Bean and Albert Litvin, 766.

Proposed Specifications for Portland Blast-Furnace Slag Cement. Report of Committee C-1, Appendix II, 162.

The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer, 732. Discussion, 753.

Adhesives.

Adhesives. Report of Committee D-14, 335.

Summary of Proceedings of the Symposium on Adhesives, 1023.

Aggregates.

A Comparison of Absorption and Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 771.

Air Jet.

Determination of Gum Values by the I.P.T. and A.S.T.M. Air Jet Gum Methods—E. L. Walters and D. L. Yabroff. Published in ASTM Bulletin, No. 135, August, 1945, p. 40.

Air Permeability Apparatus.

Proposed Method of Test for Fineness of Portland Cement by Air Permeability Apparatus. Report of Committee C-1, Appendix IV, 195.

Aircraft Testing.

Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Alcohol Determination.

The Determination of the Terpene Alcohol Content of Steam-Distilled Pine Oil—V. E. Grotlisch and H. N. Burstein, 1015.

Alloy Steel.

See also **Steel.**

The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C.—D. J. McAdam, Jr., G. W. Geil, and R. W. Mebs, 448. Discussion, 482.

Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 92.

Filler Metal. Report of Joint Committee, 94.

Fracture Testing of Alloy Steels for Aircraft Engine Forgings—R. D. Haworth, Jr. and A. F. Christian, 407. Discussion, 441.

Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 87.

Alloys, Non-Ferrous.

See also **Aluminum; Brass; Bronze; Copper; Magnesium; Zinc.**

Cast-to-Size Impact Specimens for Aluminum Sand Casting Alloys—R. A. Quadt, p. 705.

Chemical Analysis of Metals. Report of Committee E-3, 391.
Compression Testing of Magnesium Alloy Sheet—A. A. Moore and J. C. McDonald, p. 698.
Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 111.
Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 96.
Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 105.
The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid—David J. Mack, 629.
Die-Cast Metals and Alloys. Report of Committee B-6, 134.
The Effect of the Iron Content of Cupro-Nickel on Its Corrosion Resistance in "Sea Water"—A. W. Tracy and R. L. Hungerford, 591. Discussion, 613.
Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.
Electrodeposited Metallic Coatings. Report of Committee B-8, 149.
Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 137.
Non-Ferrous Metals and Alloys. Report of Committee B-2, 102.
Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 120.
Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, Appendix I, 141.

Aluminum.

Cast-to-Size Impact Specimens for Aluminum Sand Casting Alloys—R. A. Quadt, 705.
Chemical Analysis of Metals. Report of Committee E-3, 391.
A Comparison of the Performance of Anodic Coatings Exposed to Salt Spray and to the Weather—Junius D. Edwards. Report of Committee B-7, Appendix II, 146.
Die-Cast Metals and Alloys. Report of Committee B-6, 134.
Filler Metal. Report of Joint Committee, 94.
Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 137.
Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, Appendix I, 141.

Analysis of Soils.

A New Method for the Mechanical Analysis of Soils—Raul Valle-Rodas. Published in ASTM BULLETIN, No. 135, August, 1945, p. 44.

Analytical Chemistry.

See **Chemical Analysis.** (Methods of analysis, testing, etc., are also indexed under the materials and subjects covered by them.)

Annapolis Exposure Tests.

Record of failures in atmospheric exposure tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets. Report of Subcommittee III, Committee A-5, 68.

Annual Meeting.

Annual Report of the Executive Committee, 21.
Summary of Proceedings of the Forty-eighth Annual Meeting, 1.

Anodic Coatings.

Comparison of the Performance of Anodic Coatings Exposed to Salt Spray and to the Weather—Junius D. Edwards. Report of Committee B-7, Appendix II, 146.
Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 137.

Anthracite.

See **Coal.**

Antiseptic Fabrics.

A Suggested Method for Thorough Testing of Antiseptic Fabrics—Louis C. Barail. Published in ASTM BULLETIN, No. 136, October, 1945, p. 25.

Arc-Formed Gases.

Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.

Asbestos.

Test Criterion for an Incombustible Material —N. P. Setchkin and S. H. Ingberg, 866. Discussion, 876.
Textile Materials. Report of Committee D-13, 323.

Asbestos Cement Products.

Standards. Report of Committee E-10, 395.

Askarels.

Electrical Insulating Materials. Report of Committee D-9, 275.
Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.

Assemblies Testing.

Preparations for the Future of the A.S.T.M. Annual Address by the President, P. H. Bates, 14.
Relation Between Life Testing and Conventional Tests of Materials—R. E. Peterson. Published in ASTM BULLETIN, No. 133, March, 1945, p. 9.

Atmospheric Exposure.

See **Corrosion; Weathering.**

Autoclave Tests.

Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Snyder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165.

B

Barbed Wire.

Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

Bast and Leaf Fibers.

Textile Materials. Report of Committee D-13, 323.

Bearing Metal.

Non-Ferrous Metals and Alloys. Report of Committee B-2, 102.

Bekk Smoothness Tester.

Proposed Methods of Test for Smoothness of Paper. Report of Committee D-6, Appendix, 260.

Benzene.

Aromatic Petroleum Solvents. Report of Special Committee, Committee D-16, Appendix II, 348.
Cooperative Distillation Tests of Aromatic Hydrocarbons. Report of Committee D-16, Appendix I, 340.
Industrial Aromatic Hydrocarbons. Report of Committee D-16, 337.
Proposed Method of Test for Total Olefinic and Aromatic Hydrocarbons in Gasoline. Report of Committee D-2, Appendix II, 247.

Bituminous Coal.

See **Coal.**

Bituminous Materials.

See **Petroleum Products; Roofing Materials.**

Blaine Air Permeability Apparatus.

Proposed Method of Test for Fineness of Portland Cement by Air Permeability Apparatus. Report of Committee C-1, Appendix IV, 195.

Boiler Feedwater.

See also **Water.**
Water for Industrial Uses. Report of Committee D-19, 356.

Bond Strength.

The Effect of Repeated Loading on the Bond Strength of Concrete—C. W. Muhlenbruch, 824.

Bonded-Wire Strain Gage.

A Rubber Housing for Waterproofing the Bonded-Wire Strain Gage—Douglas McHenry. Published in ASTM BULLETIN, No. 133, March, 1945, p. 18.

Boxes.

Shipping Containers. Report of Committee D-10, 311.

Brass.

Chemical Analysis of Metals. Report of Committee E-3, 391.
Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 111.
Die-Cast Metals and Alloys. Report of Committee B-6, 134.
Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 120.

Brick.

Manufactured Masonry Units. Report of Committee C-15, 214.
Refractories. Report of Committee C-8, 208.

Brinnell Hardness.

See **Hardness Testing.**

Bronze.

See also **Copper.**
Chemical Analysis of Metals. Report of Committee E-3, 391.
Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 111.
Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 120.

Building Brick.

See **Brick.**

By-laws.

Proposed Amendments of Society By-laws, 2, 34.

C

C. F. R. Engine.

Proposed Revisions in the Methods of Test for Knock Characteristics of Motor Fuels (D 357 - 45) and of Aviation Fuels (D 614 - 44 T). Report of Technical Committee A on Gasoline, Committee D-2, 233.

Cable.

Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 96.

Calibration.

Proposed Method of Test for Fineness of Portland Cement by Air Permeability Apparatus. Report of Committee C-1, Appendix IV, 195.
Proposed Methods of Test for Smoothness of Paper. Report of Committee D-6, Appendix, 260.

Carbon-Molybdenum Steel.

See **Alloy Steel.**

Castings.

See also **Alloy Steel; Aluminum; Brass; Bronze; Copper; Die Castings; Magnesium; Malleable Iron; Steel.**
Cast-to-Size Impact Specimens for Aluminum Sand Casting Alloys—R. A. Quadt, 705.
Observations on the Appearance Welding of Malleable Castings—H. A. Schwartz, Ira Young and James Hedberg, 618. Discussion, 626.
Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Cast-to-Size Specimens.

Cast-to-Size Impact Specimens for Aluminum Sand Casting Alloys—R. A. Quadt, 705.

Cavitation.

Memo on Cavitation—Frank N. Speller. Published in ASTM BULLETIN, No. 133, March, 1945, p. 21.

Cement.

Cement. Report of Committee C-1, 156.
Effect of Heat on Portland Cements Containing Vinsol Resin—Leonard Bean and Albert Litvin, 766.
Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars—G. J. Fink and Emil Trattner, 723.
Proposed Method of Test for Fineness of Portland Cement by Air Permeability Apparatus. Report of Committee C-1, Appendix IV, 195.
Proposed Recommendations Affecting Standards on Cement. Report of Committee C-1, Appendix I, 160.
Proposed Specifications for Portland Blast-Furnace Slag Cement. Report of Committee C-1, Appendix II, 162.
Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Snyder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165.
The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer, 732. Discussion, 753.
Thermal Insulating Cement. Report of Committee C-16, 216.

Chain Link Fence.

Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

Charter of Society.

Proposed Amendments of Society Charter, 2, 35.

Chemical Analysis.

Cement. Report of Committee C-1, 156.
Chemical Analysis of Metals. Report of Committee E-3, 391.

Chlorides.

Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.

Chromium.

Electrodeposited Metallic Coatings. Report of Committee B-8, 149.

Chromium-Nickel Alloys.

See **Alloy Steel.**

Clad Steel.

See **Corrosion-Resisting Alloy Steels.**

Clay Pipe.

Clay Pipe. Report of Committee C-4, 200.

Cleaners.

Metal Cleaning: I—Indirect Performance Tests—Jay C. Harris, 985.
Metal Cleaning: II—Soil Removal Performance Methods—Jay C. Harris, 997.

Coal.

Coal and Coke. Report of Committee D-5, 255.

Coated Fabrics.

See **Rubber Products.**

Coating Thickness Gage.

A New Coating Thickness Gage—S. Lipson. Published ASTM BULLETIN, No. 135, August, 1945, p. 20.

Coatings, Surface-Conversion.

Surface-Conversion Coatings—George W. Jernstedt. Published in ASTM BULLETIN, No. 137, December, 1945, p. 29.

Cohesive Strength.

The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C.—D. J. McAdam, Jr., G. W. Geil, and R. W. Mebs, 448. Discussion, 482.

Coke.

Coal and Coke. Report of Committee D-5, 255.

Color Test.

Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.
Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Compression Testing.

Compression Testing of Magnesium Alloy Sheet—A. A. Moore and J. C. McDonald, 698.
Effect of Dimensions of Specimens upon the Precision of Strength Data—John Tucker, Jr., 952. Discussion, 960.
Effect of Length on the Strength of Compression Test Specimens—J. Tucker, Jr., 976.
The Effect of Specimen Shape on the Compressive Strength Properties of Laterally Supported Plywood Specimens—J. A. Liska, 935.
Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete—Bryant Mather, 802. Discussion, 810.
The Maximum Stresses Present at Failure of Brittle Materials—J. Tucker, Jr., 961. Discussion, 974.
Single-Strip Compression Test for Sheet Materials—Harry LaTour and Don S. Wolford, 671. Discussion, 689.
The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer, 732. Discussion, 753.

Concrete.

Automatic Accelerated Freezing-and-Thawing Apparatus for Concrete—Charles E. Wuerpel and Herbert K. Cook, 813.
Effect of Length on the Strength of Compression Test Specimens—J. Tucker, Jr., 976.

The Effect of Repeated Loading on the Bond Strength of Concrete—C. W. Muhlenbruch, 824.

Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete—Bryant Mather, 802. Discussion, 810.

Manufactured Masonry Units. Report of Committee C-15, 214.

The Maximum Stresses Present at Failure of Brittle Materials—J. Tucker, Jr., 961. Discussion, 974.

Stress Conditions for the Failure of Saturated Concrete and Rock—K. Terzaghi, 777. Discussion, 793.

Conditioning.

Electrical Insulating Materials. Report of Committee D-9, 275.

Conductors.

Electrical Conductivity of Conductors—L. F. Roehmann, 711.

Consistency.

Proposed Revision of the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 - 38 T). Report of Committee C-7, Appendix, 206.

he Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer, 732. Discussion, 753.

Consumer Goods.

Standards. Report of Committee E-10, 395.

Contact Metals.

Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.

Containers.

Shipping Containers. Report of Committee D-10, 311.

Copper.

Chemical Analysis of Metals. Report of Committee E-3, 391.

Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 111.

The Effect of the Iron Content of Cupro-Nickel on Its Corrosion Resistance in "Sea Water"—A. W. Tracy and R. L. Hungerford, 591. Discussion, 613.

Non-Ferrous Metals and Alloys. Report of Committee B-2, 102.

Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 152.

Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 120.

Copper-Bearing Steel.

See also **Steel.**

Corrosion of Iron and Steel. Report of Committee A-5, 66.

Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.

Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

Record of failures in atmospheric exposure tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets. Report of Subcommittee III, Committee A-5, 68.

Copper Covered Wires.

Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

Copper Wire.

Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 96.

Cord, Tire.

Statistical Comparison of Rayon Tire Cord Fatigue Testing Machines—C. B. Budd and L. Larrick. Published in ASTM BULLETIN, No. 136, October, 1945, p. 19.

Corrosion.

See also **Weathering.**

A Comparison of the Performance of Anodic Coatings Exposed to Salt Spray and to the Weather—Junius D. Edwards. Report of Committee B-7, Appendix II, 146.

Corrosion of Iron and Steel. Report of Committee A-5, 66.

Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 105.

The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid—David J. Mack, 629.

Corrosion *(Continued)*
- Die-Cast Metals and Alloys. Report of Committee B-6, 134.
- The Effect of the Iron Content of Cupro-Nickel on Its Corrosion Resistance in "Sea Water"—A. W. Tracy and R. L. Hungerford, 591. Discussion, 613.
- Electrodeposited Metallic Coatings. Report of Committee B-8, 149.
- Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.
- Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.
- Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 87.
- Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 137.
- Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 152.
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- A Variable Cycle Alternate Immersion Corrosion Testing Machine—C. H. Mahoney, A. L. Tarr, and K. A. Skeie, 719.

Corrosion-Resisting Alloy Steels.
- See also **Alloy Steels.**
- Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.
- Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 87.

Cotton.
- See also **Textile Materials.**
- Textile Materials. Report of Committee D-13, 323.

Crack Growth.
- A Sulfur Print Method for the Study of Crack Growth in the Corrosion-Fatigue of Metals—R. C. Brumfield, 544.

Crankcase Oils.
- See **Lubricants; Petroleum Products.**

Creep Tests.
- See **Temperature, Effect of.**

D

Deoxidation.
- Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr, 486. Discussion, 504.

Detergents.
- Metal Cleaning: I—Indirect Performance Tests—Jay C. Harris, 985.
- Metal Cleaning: II—Soil Removal Performance Methods—Jay C. Harris, 997.

Die Castings.
- Die-Cast Metals and Alloys. Report of Committee B-6, 134.

Dielectric Strength.
- Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Dimensional Stability.
- Dimensional Stability of Plastics—Robert Burns, 926.

Dipentene.
- Naval Stores. Report of Committee D-17, 349.

Dissolved Oxygen.
- Proposed Methods for Determination of Dissolved Oxygen in Industrial Waters. Published in ASTM BULLETIN, No. 137, December, 1945, p. 19.
- Proposed Methods of Test for Dissolved Oxygen in Industrial Waters. Report of Committee D-19, Appendix, 360.

Distillation Test.

Cooperative Distillation Tests of Aromatic Hydrocarbons. Report of Committee D-16, Appendix I, 340.

Dolomitic Lime.

Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars—G. J. Fink and Emil Trattner, 723.

Durability.

See **Weathering.**

Duralumin.

See **Aluminum.**

Dynamic Testing.

Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Snyder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165.

E

Effect of Specimen Size.

See **Test Specimens.**

Effect of Temperature.

See **Temperature, Effect of.**

Elastic Constants.

Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders—Gerald Pickett, 846. Discussion, 864.

Elasticity.

See **Compression Testing; Tension Testing.**

Elastomers.

See **Rubber Products.**

Electrical Conductivity.

Electrical Conductivity of Conductors—L. F. Roehmann, 711.

Electrical Insulating Materials.

Dimensional Stability of Plastics—Robert Burns, 926.

Electrical Insulating Materials. Report of Committee D-9, 275.

Electrical Insulating Materials. Report of Sectional Committee C-59, 310.

Plastics. Report of Committee D-20, 369.

Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.

Recommendations Affecting Standards on Electrical Insulating Materials. Report of Committee D-9, Appendix I, 283.

Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Electrical Tests.

Methods Used for the Measurement of the Moisture Content of Wood—M. E. Dunlap. Report of Committee D-7, Appendix, 269.

Electrical-Resistance and Heating Alloys.

Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.

Electric-Furnace Alloys.

Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.

Electrodeposited Coatings.

Corrosion of Iron and Steel. Report of Committee A-5, 66.

Electrodeposited Metallic Coatings. Report of Committee B-8, 149.

Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 152.

Recommendations Affecting Standards for Electrodeposited Metallic Coatings. Report of Committee B-8, Appendix, 154.

Electrolytic Corrosion.

Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 105.

Electronic Materials.

Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.

Elevated Temperature.

See **Temperature, Effect of.**

Emulsification Test.

Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Endurance Testing.

See **Fatigue Testing.**

Evaporation Method.

Determination of Gum Values by the I.P.T. and A.S.T.M. Air Jet Gum Methods—E. L. Walters and D. L. Yabroff. Published in ASTM BULLETIN, No. 135, August, 1945, p. 40.

Executive Committee.

Annual Report of the Executive Committee, 21.

Expansion Test.

Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Snyder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165.

Exposure Tests.

See **Corrosion; Weathering.**

F

Fabrics.

See **Textile Materials.**

Fatigue Testing.

An Automotive Tire Fatigue Machine—John N. Kenyon. Published in ASTM BULLETIN, No. 136, October, 1945, p. 9.

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The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid—David J. Mack, 629.

The Effect of Overstress in Fatigue on the Endurance Life of Steel—J. B. Kommers, 532. Discussion, 542.

Fatigue of Metals. Report of the Research Committee, 91.

Fatigue Tests of a Laminated Mitscherlich-Paper Plastic—William N. Findley, 878. Discussion, 904.

Relation Between Life Testing and Conventional Tests of Materials—R. E. Peterson. Published in ASTM BULLETIN, No. 133, March, 1945, p. 9.

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A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel—H. F. Moore, 507. Discussion, 522.

A Suggested New Parameter for Fatigue Strength Analysis—Victor Seliger. Published in ASTM BULLETIN, No. 132, January, 1945, p. 29.

A Sulfur Print Method for the Study of Crack Growth in the Corrosion-Fatigue of Metals—R. C. Brumfield, 544.

Fence.

Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

Fiberboard.

Paper and Paper Products. Report of Committee D-6, 257.

Fibers.

Textile Materials. Report of Committee D-13, 323.

Filler Metal.

Filler Metal. Report of Joint Committee, 94.

Films.

General Properties of Industrial Radiographic

Films—Herman E. Seemann. Published in ASTM BULLETIN, No. 134, May, 1945, p. 17.

Finances.

Annual Report of the Executive Committee, 21.
Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 92.

Fineness.

Proposed Method of Test for Fineness of Portland Cement by Air Permeability Apparatus. Report of Committee C-1, Appendix IV, 195.
The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer, 732. Discussion, 753.

Fire Brick.

See **Refractories.**

Fire Tests.

Fire Tests of Materials and Construction. Report of Committee C-5, 201.
Some Factors in the Interpretation of Small-Scale Tests for Fire-Retardant Wood—F. W. Gottschalk. Published in ASTM BULLETIN, No. 136, October, 1945, p. 40.

Flexure Testing.

Effect of Dimensions of Specimens upon the Precision of Strength Data—John Tucker, Jr., 952. Discussion, 960.
The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics—E. M. Schoenborn, George R. Proctor, and Jaime Carvajal, 910. Discussion, 923.
Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders—Gerald Pickett, 846. Discussion, 864.
Flexural Properties of Plastics—Summary of Test Results Obtained in Committee D-20—W. A. Zinzow. Report of Committee D-20, Appendix II, 376. Discussion, 389.

Forgings.

Fracture Testing of Alloy Steels for Aircraft Engine Forgings—R. D. Haworth, Jr. and A. F. Christian, 407. Discussion, 441.
Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Fracture Testing.

Fracture Testing of Alloy Steels for Aircraft Engine Forgings—R. D. Haworth, Jr. and A. F. Christian, 407. Discussion, 441.

Freezing-and-Thawing Test.

Automatic Accelerated Freezing-and-Thawing Apparatus for Concrete—Charles E. Wuerpel and Herbert K. Cook, 813.

Fuel Oil.

See **Petroleum Products.**

G

Galvanic Corrosion.

Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 105.

Galvanizing.

See **Zinc Coatings.**

Gal Welding.

See **Welds.**

Gaseous Fuels.

Gaseous Fuels. Report of Committee D-3, 253.

Gasoline.

Determination of Gum Values by the I.P.T. and A.S.T.M. Air Jet Gum Methods—E. L. Walters and D. L. Yabroff. Published in ASTM BULLETIN, No. 135, August, 1945, p. 40.
Petroleum Products and Lubricants. Report of Committee D-2, 228.
Proposed Method of Test for Total Olefinic and Aromatic Hydrocarbons in Gasoline. Report of Committee D-2, Appendix II, 247.
Proposed Revisions in the Methods of Test for Knock Characteristics of Motor Fuels (D 357 – 45) and of Aviation Fuels (D 614 – 44 T). Report of Technical Committee A on Gasoline, Committee D-2, 233.

Glass.

Electrical Insulating Materials. Report of Committee D-9, 275.
Glass—A Summary of Its Development as an Art and as a Science—F. C. Flint. Published in ASTM BULLETIN, No. 132, January, 1945, p. 19.

Glass Textiles.

See also **Textiles.**
Textile Materials. Report of Committee D-13, 323.

Glue.

See **Adhesives.**

Grease.

See **Lubricants.**

Gum Values.

Determination of Gum Values by the I.P.T. and A.S.T.M. Air Jet Gum Methods—E. L. Walters and D. L. Yabroff. Published in ASTM BULLETIN, No. 135, August, 1945, p. 40.

Gurley-Hill S-P-S Tester.

Proposed Methods of Test for Smoothness of Paper. Report of Committee D-6, Appendix, 260.

H

Hard Rubber.

See **Rubber Products.**

Hardness Testing.

Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr, 486. Discussion, 504.

Heat Distortion Recorder.

An Automatic Heat Distortion Recorder for Plastics—George A. Heirholzer and R. F. Boyer. Published in ASTM BULLETIN, No. 134, May, 1945, p. 37.

Heat Effect.

Effect of Heat on Portland Cements Containing Vinsol Resin—Leonard Bean and Albert Litvin, 766.

Heavy-Wall Pipe.

The Manufacture of Heavy-Wall Pipe 12$\frac{3}{4}$ to 24 In. Outside Diameter—E. C. Wright. Published in ASTM BULLETIN, No. 133, March, 1945, p. 19.

High-Temperature Materials.

See also **Refractories; Temperature, Effect of.**
Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 92.

High-Temperature Testing.

See **Temperature, Effect of.**

Hydrocarbons, Aromatic Industrial.

See **Benzene; Solvents; Toluene; Xylene.**

Hydrogen Ion Determination.

See **pH Value.**

I

Ignition Temperature.

Test Criterion for an Incombustible Material —N. P. Setchkin and S. H. Ingberg, 866. Discussion, 876.

Immersion Testing.

Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 105.
A Variable Cycle Alternate Immersion Corrosion Testing Machine—C. H. Mahoney, A. L. Tarr, and K. A. Skeie, 719.

Incombustible Materials.

Test Criterion for an Incombustible Material —N. P. Setchkin and S. H. Ingberg, 866. Discussion, 876.

Industrial Aromatic Hydrocarbons.

See **Benzene; Solvents; Toluene; Xylene.**
Industrial Aromatic Hydrocarbons. Report of Committee D-16, 337.

Industrial Waters.

See **Water.**

Insulating Materials.

See **Electrical Insulating Materials; Refractories; Thermal Insulating Materials.**

Iron.

See also **Malleable Iron; Wrought Iron.**
Corrosion of Iron and Steel. Report of Committee A-5, 66.
Filler Metal. Report of Joint Committee, 94.
Observations on the Appearance Welding of Malleable Castings—H. A. Schwartz, Ira Young, and James Hedberg, 618. Discussion, 626.

Iron-Chromium-Nickel Alloys.

See **Corrosion-Resisting Alloy Steels; Electrical-Resistance and Heating Alloys.**

K

Knock Characteristics.

Proposed Revisions in the Methods of Test for Knock Characteristics of Motor Fuels (D 357 – 45) and of Aviation Fuels (D 614 – 44 T). Report of Technical Committee A on Gasoline, Committee D-2, 233.

L

Lacquers.

See also **Electrical Insulating Materials.**
Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 220.

Laminated Plastics.

The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics—E. M. Schoenborn, George R. Proctor, and Jaime Carvajal, 910. Discussion, 923.
Fatigue Tests of a Laminated Mitscherlich-Paper Plastic—William N. Findley, 878. Discussion, 904.

Latex.

See **Rubber Products.**

Lead.

The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid—David J. Mack, 629.
Non-Ferrous Metals and Alloys. Report of Committee B-2, 102.
Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-9, 152.

Lead Coated Wire.

Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

Life Testing, Oil.

Life Testing of Lubrication Oil—H. C. Mougey. Published in ASTM BULLETIN, No. 132, January, 1945, p. 15.

Light Aging Test.

See **Weathering.**

Light Metals.

See **Aluminum; Magnesium.**

Lime.

Lime. Report of Committee C-7, 203.
Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars—G. J. Fink and Emil Trattner, 723.
Proposed Revision of the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 – 38 T). Report of Committee C-7, Appendix, 206.

Linoleum.

A New Machine for Measuring Wear Resistance of Walkway Materials—A. W. Cizek, Jr., D. H. Kallas, and H. Nestlen, 943. Discussion, 951.

Liquid Dielectrics.

See **Askarels; Electrical Insulating Materials; Transformer Oils.**

Low-Temperature Testing.

See **Temperature, Effect of.**

Lubricants.

Cooperative Committees Developing Test Methods for Lubricating Greases—T. G. Roehner. Published in ASTM BULLETIN, No. 133, March, 1945, p. 31.
Life Testing of Lubrication Oil—H. C. Mougey. Published in ASTM BULLETIN, No. 132, January, 1945, p. 15.
Past History of A.S.T.M. Lubricating Grease

Lubricants (*Continued*)
  Test Methods—H. A. McConville. Published in ASTM BULLETIN, No. 133, March, 1945, p. 29.
  Petroleum Products and Lubricants. Report of Committee D-2, 228.
  Proposed Method of Test for Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants. Report of Committee D-2, Appendix I, 244.
  Results of Tests on Method for Estimating Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants. Report of Subcommittee XVI, Committee D-2, 237.

M

Magnesium.
  Compression Testing of Magnesium Alloy Sheet—A. A. Moore and J. C. McDonald, 698.
  Die-Cast Metals and Alloys. Report of Committee B-6, 134.
  Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 137.
  Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, Appendix I, 141.

Magnetic Particle Testing.
  Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Malleable Iron.
  Observations on the Appearance Welding of Malleable Castings—H. A. Schwartz, Ira Young, and James Hedberg, 618. Discussion, 626.

Masonry Materials.
  Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars—G. J. Fink and Emil Trattner, 723.
  Manufactured Masonry Units. Report of Committee C-15, 214.
  Mortars for Unit Masonry. Report of Committee C-12, 213.

Mechanical Analysis of Soils.
  A New Method for the Mechanical Analysis of Soils—Raul Valle-Rodas. Published in ASTM BULLETIN, No. 135, August, 1945, p. 44.

Membership.
  Annual Report of the Executive Committee, 21.

Merriman Slab Test.
  Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Synder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165, 193.

Merriman Sugar Solubility Test.
  Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Synder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165, 194.

Metal Cleaning.
  Metal Cleaning: I—Indirect Performance Tests—Jay C. Harris, 985.
  Metal Cleaning: II—Soil Removal Performance Methods—Jay C. Harris, 997.

Metallography.
  Observations on the Appearance Welding of Malleable Castings—H. A. Schwartz, Ira Young, and James Hedberg, 618. Discussion, 626.
  Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr, 486. Discussion, 504.

Mica.
  Electrical Insulating Materials. Report of Committee D-9, 275.

Modulus of Elasticity.

Single-Strip Compression Test for Sheet Materials—Harry LaTour and Don S. Wolford, 671. Discussion, 689.

Modulus of Rupture.

The Maximum Stresses Present at Failure of Brittle Materials—J. Tucker, Jr., 961. Discussion, 974.

Moisture Test.

Methods Used for the Measurement of the Moisture Content of Wood—M. E. Dunlap. Report of Committee D-7, Appendix, 269.

Molded Insulating Materials.

See **Electrical Insulating Materials; Plastics; Thermal Insulating Materials.**

Molybdenum Steel.

See also **Alloy Steel.**
Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr, 486. Discussion, 504.

Mortar.

Lime. Report of Committee C-7, 203.
Mortars for Unit Masonry. Report of Committee C-12, 213.
Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars—G. J. Fink and Emil Trattner, 723.
The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates and John R. Dwyer, 732. Discussion, 753.

Motor Fuel.

See **Gasoline; Petroleum Products.**

Motor Oils.

See **Lubricants; Petroleum Products.**

N

Natural Building Stone.

See **Aggregates.**

Naval Stores.

Naval Stores. Report of Committee D-17, 349

Neutralization Number.

Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 48.
Introduction—H. P. Ferguson.
Neutralization Number from the Viewpoint of the Industrial Engineer—C. L. Pope.
Neutralization Number from the Viewpoint of the Turbine Engineer—I—F. C. Linn.
Neutralization Number from the Viewpoint of the Turbine Engineer—II—G. H. von Fuchs.
Neutralization Number from the Viewpoint of the Automotive Engineer—H. R. Wolf.
A Comparison of the Salt Method with A.S.T.M. Method for Determining the Acidity of Lubricating Oils—C. M. Loane.

Nickel.

The Effect of the Iron Content of Cupro-Nickel on Its Corrosion Resistance in "Sea Water"—A. W. Tracy and R. L. Hungerford, 591. Discussion, 613.
Electrodeposited Metallic Coatings. Report of Committee B-8, 149.
Non-Ferrous Metals and Alloys. Report of Committee B-2, 102.

Nickel-Chromium Alloys.

See **Alloy Steel; Corrosion-Resisting Alloy Steel.**

Nickel-Copper Alloys.

Non-Ferrous Metals and Alloys. Report of Committee B-2, 102.

Nickel Steel.

See also **Alloy Steel.**
A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere—H. R. Copson, 554. Discussion, 581.

Notch Sensitivity.

A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel—H. F. Moore, 507. Discussion, 522.

O

Oven Aging.

High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds—G. D. McCarthy, A. E. Juve, H. Boxser, M. Sanger, S. R. Doner, E. N. Cunningham, J. F. McWhorter, and R. H. Crossley. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Overstress Effect.

The Effect of Overstress in Fatigue on the Endurance Life of Steel—J. B. Kommers, 532. Discussion, 542.

Oxygen.

Proposed Methods of Test for Dissolved Oxygen in Industrial Waters. Report of Committee D-19, Appendix, 360.

P

Paint.

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Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 220.

Paper.

Electrical Insulating Materials. Report of Committee D-9, 275.

Paper and Paper Products. Report of Committee D-6, 257.

Proposed Methods of Test for Smoothness of Paper. Report of Committee D-6, Appendix, 260.

Shipping Containers. Report of Committee **D-10, 311.**

Paper Laminated Plastic.

Fatique Tests of a Laminated Mitscherlich-Paper Plastic—William N. Findley, 878. Discussion, 904.

Papers and Publications.

Annual Report of the Executive Committee, 21.

Preparations for the Future of the A.S.T.M. Annual Address by the President, P. H. Bates, 14.

Parameter.

A Suggested New Parameter for Fatique Strength Analysis—Victor Seliger. Published in ASTM BULLETIN, No. 132, January, 1945, p. 29.

Particle Testing.

Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Paul's Water Floc Test.

Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Synder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165, 194.

Paving Materials.

See **Aggregates; Brick; Cement; Concrete; Soils.**

Penetration.

See **Consistency.**

Performance Tests.

Metal Cleaning: I—Indirect Performance Tests—Jay C. Harris, 985.

Metal Cleaning: II—Soil Removal Performance Methods—Jay C. Harris, 997.

Permanence.

Summary of Proceedings of the Symposium, on Adhesives, 1023.

Permeability.

Proposed Method of Test for Fineness of Portland Cement by Air Permeability Apparatus. Report of Committee C-1, Appendix IV, 195.

Petroleum Products.

Aromatic Petroleum Solvents. Report of Special Committee, Committee D-16, Appendix II, 348.

Cooperative Committees Developing Test Methods for Lubricating Greases—T. G. Roehner. Published in ASTM BULLETIN, No. 133, March, 1945, p. 31.

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Petroleum Products and Lubricants. Report of Committee D-2, 228.
Proposed Method of Test for Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants. Report of Committee D-2, Appendix I, 244.
Proposed Method of Test for Total Olefinic and Aromatic Hydrocarbons in Gasoline. Report of Committee D-2, Appendix II, 247.
Results of Tests on Method for Estimating Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants. Report of Subcommittee XVI, Committee D-2, 237.
Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 48.
  Introduction—H. P. Ferguson.
  Neutralization Number from the Viewpoint of the Industrial Engineer—C. L. Pope.
  Neutralization Number from the Viewpoint of the Turbine Engineer—I—F. C. Linn.
  Neutralization Number from the Viewpoint of the Turbine Engineer—II—G. H. von Fuchs.
  Neutralization Number from the Viewpoint of the Automotive Engineer—H. R. Wolf.
  A Comparison of the Salt Method with A.S.-T.M. Method for Determining the Acidity of Lubricating Oils—C. M. Loane.

pH Value.

The pH of Some Standard Buffer Solutions from 0 to 60 C. and the Calibration of Glass Electrode pH Meters—George G. Manov and S. F. Acree. Published in ASTM BULLETIN, No. 137, December, 1945, p. 25.

Phenolic Materials.

See **Electrical Insulating Materials; Plastics.**

Pigments.

Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 220.

Pine Oil.

The Determination of the Terpene Alcohol Content of Steam-Distilled Pine Oil—V. E. Grotlisch and H. N. Burstein, 1015.
Naval Stores. Report of Committee D-17, 349.

Pipe and Piping Materials.

Clay Pipe. Report of Committee C-4, 200.
The Manufacture of Heavy-Wall Pipe $12\frac{3}{4}$ to 24 In. Outside Diameter—E. C. Wright. Published in ASTM BULLETIN, No. 133, March, 1945, p. 19.

Plastic Refractories.

See **Refractories.**

Plastics.

See also **Electrical Insulating Materials.**
An Automatic Heat Distortion Recorder for Plastics—George A. Heirholzer and R. F. Boyer. Published in ASTM BULLETIN, No. 134, May, 1945, p. 37.
Dimensional Stability of Plastics—Robert Burns, 926.
The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics—E. M. Schoenborn, George R. Proctor, and Jaime Carvajal, 910. Discussion, 923.
Electrical Insulating Materials. Report of Committee D-9, 275.
Fatigue Tests of a Laminated Mitscherlich-Paper Plastic—William N. Findley, 878. Discussion, 904.
Flexural Properties of Plastics—Summary of Test Results Obtained in Committee D-20—W. A. Zinzow. Report of Committee D-20, Appendix II, 376. Discussion, 389.
Plastics. Report of Committee D-20, 369.
Recommendations Affecting Standards on Plastics. Report of Committee D-20, Appendix I, 374.
A Simplified Method for the Determination of the Specific Gravity of Wood and Plastics—E. George Stern and Paul S. Dear. Published in ASTM BULLETIN, No. 135, August, 1945, p. 35.

Plating.

See **Electrodeposited Coatings.**

Plywood.

The Effect of Specimen Shape on the Compressive Strength Properties of Laterally Supported Plywood Specimens—J. A. Liska, 935.

Wood. Report of Committee D-7, 265.

Popping and Pitting Test.

Proposed Revision of the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 - 38 T). Report of Committee C-7, Appendix, 206.

Pore Water Pressure.

Stress Conditions for the Failure of Saturated Concrete and Rock—K. Terzaghi, 777. Discussion, 793.

Portland Cement.

See **Cement.**

Pour Point.

Proposed Method of Test for Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants. Report of Committee D-2, Appendix I, 244.

Results of Tests on Method for Estimating Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants. Report of Subcommittee XVI, Committee D-2, 237.

Power Factor.

Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Presidential Address.

Preparations for the Future of the A.S.T.M. Annual Address by the President, P. H. Bates, 14.

Publications.

See **Papers and Publications.**

Pull-Out Specimen.

The Effect of Repeated Loading on the Bond Strength of Concrete—C. W. Muhlenbruch, 824.

Q

Quicklime.

See **Lime.**

R

Radio Materials.

See **Electronic Materials.**

Radiographic Films.

General Properties of Industrial Radiographic Films—Herman E. Seemann. Published in ASTM BULLETIN, No. 134, May, 1945, p. 17.

Railroad Equipment Testing.

Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Rayon.

Textile Materials. Report of Committee D-13, 323.

Rayon Tire Cord.

Comparative Fatigue Test Data—C. S. Venable. Published in ASTM BULLETIN, No. 136, October, 1945, p. 17.

Standard Fatigue Tester for Use by the Rayon Manufacturers—Report to Committee D-13 —W. H. Bradshaw. Published in ASTM BULLETIN, No. 136, October, 1945, p. 13.

Statistical Comparison of Rayon Tire Cord Fatigue Testing Machines—C. B. Budd and L. Larrick. Published in ASTM BULLETIN, No. 136, October, 1945, p. 19.

Refractive Index.

Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.

Refractories.

Refractories. Report of Committee C-8, 208.

Repeated Loading.

The Effect of Repeated Loading on the Bond Strength of Concrete—C. W. Muhlenbruch, 824.

Research.

Annual Report of the Executive Committee, 21.

Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 92.
Fatigue of Metals. Report of the Research Committee, 91.

Resins.

See also **Plastics; Shellac; Soaps and Detergents; Varnish.**

Road Materials.

See also **Aggregates; Brick; Cement; Concrete; Soils.**
Soils for Engineering Purposes. Report of Committee D-18, 354.

Rock.

Stress Conditions for the Failure of Saturated Concrete and Rock—K. Terzaghi, 777. Discussion, 793.

Rockwell Hardness.

See **Hardness Testing.**

Roofing Materials.

Fire Tests of Materials and Construction. Report of Committee C-5, 201.

Rosin.

Naval Stores. Report of Committee D-17, 349.

Rubber Products.

A Rubber Housing for Waterproofing the Bonded-Wire Strain Gage—Douglas McHenry. Published in ASTM BULLETIN, No. 133, March, 1945, p. 18.
Rubber and Rubber-Like Materials. Report of Committee D-11, 312.

Rusting.

A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere—H. R. Copson, p. 554. Discussion, 581.

S

Salt Spray Tests.

See also **Corrosion.**
A Comparison of the Performance of Anodic Coatings Exposed to Salt Spray and to the Weather—Junius D. Edwards. Report of Committee B-7, Appendix II, 146.
Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 105.

Sampling.

Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.

Sand.

See also **Aggregates.**
A Comparison of Absorption and Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 771.

Saturation.

Stress Conditions for the Failure of Saturated Concrete and Rock—K. Terzaghi, 777. Discussion, 793.

Sea Water Corrosion.

See also **Corrosion; Immersion Testing.**
The Effect of the Iron Content of Cupro-Nickel on Its Corrosion Resistance in "Sea Water"—A. W. Tracy and R. L. Hungerford, 591. Discussion, 613.

Shellac.

Electrical Insulating Materials. Report of Committee D-9, 275.
Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 220.

Ship Tests.

Practical Electric Resistance Strain Gage Procedures for Structural Tests on Ships—W. V. Bassett, 651. Discussion, 667.

Shipping Containers.

Shipping Containers. Report of Committee D-10, 311.

Sheet Material

Compression Testing of Magnesium Alloy Sheet—A. A. Moore and J. C. McDonald, 698.
Single-Strip Compression Test for Sheet Materials—Harry LaTour and Don S. Wolford, 671. Discussion, 689.

Simulated Service Tests.

Relation Between Life Testing and Conventional Tests of Materials—R. E. Peterson. Published in ASTM BULLETIN, No. 133, March, 1945, p. 9.

Size Effect.

A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel—H. F. Moore, 507. Discussion, 522.

Slag Cement.

Proposed Specifications for Portland Blast-Furnace Slag Cement. Report of Committee C-1, Appendix II, 162.

Sludge Test.

Report on Results of Questionnaire to Utilites Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Smoothness Test.

Proposed Methods of Test for Smoothness of Paper. Report of Committee D-6, Appendix, 260.

Soaps and Detergents.

Soaps and Other Detergents. Report of Committee D-12, 319.

Tentative Revision of Standard Methods of Sampling and Chemical Analysis of Soaps and Soap Products (D 460 - 44). Report of Committee D-12, Appendix, 322.

Soil Removal.

Metal Cleaning. II—Soil Removal Performance Methods—Jay C. Harris, 997.

Soils.

Soils for Engineering Purposes. Report of Committee D-18, 354.

A New Method for the Mechanical Analysis of Soils—Raul Valle-Rodas. Published in ASTM BULLETIN, No. 135, August, 1945, p. 44.

Solder.

Non-Ferrous Metals and Alloys. Report of Committee B-2, 102.

Solvents.

Aromatic Petroleum Solvents. Report of Special Committee, Committee D-16, Appendix II, 348.

Cooperative Distillation Tests of Aromatic Hydrocarbons. Report of Committee D-16, Appendix I, 340.

Proposed Method of Test for Total Olefinic and Aromatic Hydrocarbons in Gasoline. Report of Committee D-2, Appendix II, 247.

Sonic Testing.

See **Dynamic Testing.**

Soundness Tests.

A Comparison of Absorption and Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 771.

Specific Gravity.

Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.

A Simplified Method for the Determination of the Specific Gravity of Wood and Plastics—E. George Stern and Paul S. Dear. Published in ASTM BULLETIN, No. 135, August, 1945, p. 35.

Specimen Shape, Effect of.

Effect of Dimensions of Specimens upon the Precision of Strength Data—John Tucker, Jr., 952. Discussion, 960.

Effect of Length on the Strength of Compression Test Specimens—J. Tucker, Jr., 976.

The Effect of Specimen Shape on the Compressive Strength Properties of Laterally Supported Plywood Specimens—J. A. Liska, 935.

Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete—Bryant Mather, 802. Discussion, 810.

The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics—E. M. Schoenborn, George R. Proctor, and Jaime Carvajal, 910. Discussion, 923.

Sponge Rubber.

See **Rubber Products.**

Stainless Steel.

See **Alloy Steel; Corrosion-Resisting Alloy Steel.**

Standardization.

Annual Report of the Executive Committee, 21.
Preparations for the Future of the A.S.T.M. Annual Address by the President, P. H. Bates, 14.
Standards. Report of Committee E-10, 395.
Summary of Proceedings of the Forty-eighth Annual Meeting, 1.

Statistical Analysis.

Effect of Dimensions of Specimens upon the Precision of Strength Data—John Tucker, Jr., 952. Discussion, 958.
The Maximum Stresses Present at Failure of Brittle Materials—J. Tucker, Jr., 961. Discussion, 974.

Steel.

Chemical Analysis of Metals. Report of Committee E-3, 391.
Corrosion of Iron and Steel. Report of Committee A-5, 66.
The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C.—D. J. McAdam, Jr., G. W. Geil, and R. W. Mebs, 448. Discussion, 482.
The Effect of Overstress in Fatigue on the Endurance Life of Steel—J. B. Kommers, 532. Discussion, 542.
Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 92.
Electrodeposited Metallic Coatings. Report of Committee B-8, 149.
Fatigue of Metals. Report of the Research Committee, 91.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.
Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.
Filler Metal. Report of Joint Committee, 94.
Fracture Testing of Alloy Steels for Aircraft Engine Forgings—R. D. Haworth, Jr. and A. F. Christian, 407. Discussion, 441.
Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 87.
Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 152.
Record of failures in atmospheric exposure tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets. Report of Subcommittee III, Committee A-5, 68.
Single-Strip Compression Test for Sheet Materials—Harry LaTour and Don S. Wolford, 671. Discussion, 689.
Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr, 486. Discussion, 504.
A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel—H. F. Moore, 507. Discussion, 522.
A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere—H. R. Copson, 554. Discussion, 581.

Stone.

See **Aggregates.**

Storage Battery Lead.

The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid—David J. Mack, 629.

Strain Gage.

Practical Electric Resistance Strain Gage Procedures for Structural Tests on Ships—W. V. Bassett, 651. Discussion, 667.
A Rubber Housing for Waterproofing the Bonded-Wire Strain Gage—Douglas McHenry. Published in ASTM BULLETIN, No. 133, March, 1945, p. 18.

Stress Analysis

Practical Electric Resistance Strain Gage Procedures for Structural Tests on Ships—W. V. Bassett, 651. Discussion, 667.
Stress Conditions for the Failure of Saturated Concrete and Rock—K. Terzaghi, 777. Discussion, 793.
A Suggested New Parameter for Fatigue Strength Analysis—Victor Seliger. Published in ASTM BULLETIN, No. 132, January, 1945, p. 29.

Structural Steel.

See **Steel.**

Sulfate Resistance.

Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements—Dalton G. Miller and Charles G. Snyder. Report of the Working Committee on Sulfate Resistance, Committee C-1, Appendix III, 165.

Sulfonates, Petroleum.

See **Soaps and Detergents**

Sulfur Print Method.

A Sulfur Print Method for the Study of Crack Growth in the Corrosion-Fatigue of Metals—R. C. Brumfield, 544.

Summary of Proceedings.

Summary of Proceedings of the Forty-eighth Annual Meeting, 1.

Surface-Conversion.

Surface-Conversion Coatings—George W. Jernstedt. Published in ASTM BULLETIN, No. 137, December, 1945, p. 29.

Synthetic Detergents.

See **Soaps and Detergents.**

Synthetic Rubbers.

High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds—G. D. McCarthy, A. E. Juve, H. Boxser, M. Sanger, S. R. Doner, E. N. Cunningham, J. F. McWhorter, and R. H. Crossley. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Rubber and Rubber-Like Materials. Report of Committee D-11, 312.

T

Tall Oil.

Naval Stores. Report of Committee D-17, 349.

Teak Wood.

A New Machine for Measuring Wear Resistance of Walkway Materials—A. W. Cizek, Jr., D. H. Kallas, and H. Nestlen, 943. Discussion, 951.

Temperature, Effect of.

The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C.—D. J. McAdam, Jr., G. W. Geil, and R. W. Mebs, 448. Discussion, 482.

Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 92.

Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.

Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice—G. V. Smith, R. F. Miller, and C. O. Tarr, 486. Discussion, 504.

Templin Award.

Richard L. Templin Award. Annual Report of the Executive Committee, 48.

Tension Testing.

Effect of Dimensions of Specimens upon the Precision of Strength Data—John Tucker, Jr., 952. Discussion, 960.

The Maximum Stresses Present at Failure of Brittle Materials—J. Tucker, Jr., 961. Discussion, 974.

The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer, 732. Discussion, 753.

Terne Plate.

Performance Tests, atmospheric exposure tests of electroplated coatings on steel. Report of Subcommittee II, Committee B-8, 152.

Terpene Alcohol.

The Determination of the Terpene Alcohol Content of Steam-Distilled Pine Oil—V. E. Grotlisch and H. N. Burstein, 1015.

Test Specimens.

Effect of Dimensions of Specimens Upon the Precision of Strength Data—John Tucker, Jr., 952. Discussion, 960.
Effect of Length on the Strength of Compression Test Specimens—J. Tucker, Jr., 976.
The Effect of Specimen Shape on the Compressive Strength Properties of Laterally Supported Plywood Specimens—J. A. Liska, 935.
The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics—E. M. Schoenborn, George R. Proctor, and Jaime Carvajal, 910. Discussion, 923.

Testing, Physical Methods of.

(Papers and reports covering methods of analysis, sampling, testing, etc., are indexed under the materials and subjects covered by them.)

Textiles.

Comparative Fatigue Test Data—C. S. Venable. Published in ASTM BULLETIN, No. 136, October, 1945, p. 17.
Recommendations Affecting Standards for Textile Materials. Report of Committee D-13, Appendix, 329.
Standard Fatigue Tester for Use by the Rayon Manufacturers—Report to Committee D-13—W. H. Bradshaw. Published in ASTM BULLETIN, No. 136, October, 1945, p. 13.
Statistical Comparison of Rayon Tire Cord Fatigue Testing Machines—C. B. Budd and L. Larrick. Published in ASTM BULLETIN, No. 136, October, 1945, p. 19.
A Suggested Method for Thorough Testing of Antiseptic Fabrics—Louis C. Barail. Published in ASTM BULLETIN. No. 136, October, 1945, p. 25.
Textile Materials. Report of Committee D-13, 323.
Tomorrow's Textiles—Yesterday's Test Methods—J. B. Goldberg. Published in ASTM BULLETIN, No. 135, August, 1945, p. 47.

Thermal Insulating Materials.

Thermal Insulating Materials. Report of Committee C-16, 216.

Thermosetting and Thermoplastic Materials.

See **Plastics.**

Thermostat Metals.

Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.

Thickness Gage.

A New Coating Thickness Gage—S. Lipson. Published in ASTM BULLETIN, No. 135, August, 1945, p. 20.

Tile.

Manufactured Masonry Units. Report of Committee C-15, 214.

Timber.

See **Wood.**

Tin.

Performance Tests, atmospheric exposure tests of electroplated coatings on steel. Report of Subcommittee II, Committee B-8, 152.

Tire Cord.

Comparative Fatigue Test Data—C. S. Venable. Published in ASTM Bulletin, No. 136, October, 1945, p. 17.
Standard Fatigue Tester for Use by the Rayon Manufacturers, Report to Committee D-13—W. W. Bradshaw. Published in ASTM BULLETIN, No. 136, October, 1945, p. 13.
Statistical Comparison of Rayon Tire Cord Fatigue Testing Machines—C. B. Budd and L. Larrick. Published in ASTM BULLETIN, No. 136, October, 1945, p. 19.

Toluene.

Aromatic Petroleum Solvents. Report of Special Committee, Committee D-16, Appendix II, 348.
Cooperative Distillation Tests of Aromatic Hydrocarbons. Report of Committee D-16, Appendix I, 340.
Industrial Aromatic Hydrocarbons. Report of Committee D-16, 337.
Proposed Method of Test for Total Olefinic and Aromatic Hydrocarbons in Gasoline. Report of Committee D-2, Appendix II, 247.

Torsion Testing.

Effect of Dimensions of Specimens upon the Precision of Strength Data—John Tucker, Jr., 952. Discussion, 960.
Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders—Gerald Pickett, 846. Discussion, 864.

Total Immersion Tests.

See **Immersion Testing.**

Traffic Paint.

Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 220.

Transformer Oils.

Electrical Insulating Materials. Report of Committee D-9, 275.
Proposed Methods of Testing Askarels. Report of Committee D-9, Appendix II, 292.
Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

V

Varnish.

Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 220.

Vibration Testing.

Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders—Gerald Pickett, 846. Discussion, 864.

Vinsol Resin.

Effect of Heat on Portland Cements Containing Vinsol Resin—Leonard Bean and Albert Litvin, 766.
The Testing of Portland Cements Containing Interground Vinsol Resin—Raymond L. Blaine, Jason C. Yates, and John R. Dwyer, 732. Discussion, 753.

Viscosity.

Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Report of Subcommittee IV, Committee D-9, Appendix III, 302.

Volume Change.

Proposed Revision of the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 - 38 T). Report of Committee C-7, Appendix, 206.

W

Walkway Materials.

A New Machine for Measuring Wear Resistance of Walkway Materials—A. W. Cizek, Jr., D. H. Kallas, and H. Nestlen, 943. Discussion, 951.

Water.

Proposed Methods for Determination of Dissolved Oxygen in Industrial Waters. Published in ASTM BULLETIN, No. 137, December, 1945, p. 19.
Proposed Methods of Test for Dissolved Oxygen in Industrial Waters. Report of Committee D-19, Appendix, 360.
Water for Industrial Uses. Report of Committee D-19, 356.

Water Retention Test.

Proposed Revision of the Tentative Methods of Physical Testing of Quicklime and Hydrated Lime (C 110 - 38 T). Report of Committee C-7, Appendix, 206.

Waterproofing.

A Rubber Housing for Waterproofing the Bonded-Wire Strain Gage—Douglas McHenry. Published in ASTM BULLETIN, No. 133, March, 1945, p. 18.

Wear Resistance.

A New Machine for Measuring Wear Resistance of Walkway Materials—A. W. Cizek, Jr., D. H. Kallas, and H. Nestlen, 943. Discussion, 951.

Weathering.

See also **Corrosion.**
A Comparison of the Performance of Anodic

Coatings Exposed to Salt Spray and to the Weather—Junius D. Edwards. Report of Committee B-7, Appendix II, 146.
Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 105.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.
Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.
Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 220.
Record of failures in atmospheric exposure tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets. Report of Subcommittee III, Committee A-5, 68.
A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere—H. R. Copson, 554. Discussion, 581.

Welds.

Filler Metal. Report of Joint Committee, 94.
Observations on the Appearance Welding of Malleable Castings—H. A. Schwartz, Ira Young and James Hedberg, 618. Discussion, 626.

Williams Smoothness Tester.

Proposed Methods of Test for Smoothness of Paper. Report of Committee D-6, Appendix, 260.

Wire.

See also **Steel.**
Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 96.
Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 108.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.
Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

Wood.

The Effect of Specimen Shape on the Compressive Strength Properties of Laterally Supported Plywood Specimens—J. A. Liska, 935.
Fire Tests of Materials and Construction. Report of Committee C-5, 201.
Methods Used for the Measurement of the Moisture Content of Wood—M. E. Dunlap. Report of Committee D-7, Appendix, 269.
A Simplified Method for the Determination of the Specific Gravity of Wood and Plastics—E. George Stern and Paul S. Dear. Published in ASTM BULLETIN, No. 135, August, 1945, p. 35.
Some Factors in the Interpretation of Small-Scale Tests for Fire-Retardant Wood—F. W. Gottschalk. Published in ASTM BULLETIN, No. 136, October, 1945, p. 40.
Wood. Report of Committee D-7, 265.

Wool.

See **Textiles.**

Wrought Iron.

Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.
Record of failures in atmospheric exposure tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets. Report of Subcommittee III, Committee A-5, 68.
Wrought Iron. Report of Committee A-2, 65.

X

X-ray.

General Properties of Industrial Radiographic Films—Herman E. Seemann. Published in ASTM BULLETIN, No. 134, May, 1945, p. 17.

Xylene.

Aromatic Petroleum Solvents. Report of Special Committee, Committee D-16, Appendix II, 348.
Cooperative Distillation Tests of Aromatic Hydrocarbons. Report of Committee D-16, Appendix I, 340.
Industrial Aromatic Hydrocarbons. Report of Committee D-16, 337.
Proposed Method of Test for Total Olefinic

Xylene (*Continued*)

and Aromatic Hydrocarbons in Gasoline. Report of Committee D-2, Appendix II, 247.

Y

Yarns.

See **Textiles.**

Z

Zinc.

Die-Cast Metals and Alloys. Report of Committee B-6, 134.

Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.

Performance Tests, atmospheric exposure tests of electroplated coatings on steel. Report of Subcommittee II, Committee B-8, 152.

Zinc Coatings.

Corrosion of Iron and Steel. Report of Committee A-5, 66.

Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 69.

Field Tests of Wire and Wire Products. Report of Wire Inspection Committee, Committee A-5, 70.

AUTHOR INDEX

VOLUME 45

A

Abrams, Duff A.
  Discussion, 755.
Acree, S. F.
  The pH of Some Standard Buffer Solutions from 0 to 60 C. and the Calibration of Glass Electrode pH Meters. Published in ASTM Bulletin, No. 137, December, 1945, p. 25.
Adams, Andrew
  A Comparison of Absorption and Soundness Tests on Maine Sands, 771.
Altieri, V. J.
  Cooperative Distillation Tests. Appendix I, Report of Committee D-16, 340.
Aston, James
  Report of Committee A-2 on Wrought Iron, 65.

B

Bahlke, W. H.
  Report of Special Committee on Aromatic Petroleum Solvents. Appendix II, Report of Committee D-16, 348.
Bailey, G. L.
  Discussion, 616.
Ball, H. J.
  Report of Committee D-13 on Textile Materials, 323.
Barail, Louis C.
  A Suggested Method for Thorough Testing of Antiseptic Fabrics. Published in the ASTM Bulletin, No. 136, October, 1945, p. 25.
Bartholomew, E. L.
  Discussion, 444.
Bash, F. E.
  Report of Committee B-4 on Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys, 108.
Bassett, W. V.
  Practical Electric Resistance Strain Gage Procedures for Structural Tests on Ships, 651. Discussion, 669.
Bates, P. H.
  Annual Report of the Executive Committee, 21.
  Preparations for the Future of the A.S.T.M. Annual Address by the President, 14.
  Report of Committee C-1 on Cement, 156.
Bean, Leonard
  Effect of Heat on Portland Cements Containing Vinsol Resin, 766.
Beard, L. C., Jr.
  Report of Subcommittee XVI, Committee D-2, on Results of Tests on Method for Estimating Maximum Pour Points of Lubricating Oils Containing Pour Point Depressants, 237.
Bennett, J. A.
  Discussion, 904.
Betz, C. E.
  Equipment for Magnetic Particle Inspection. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.
Blaine, Raymond L.
  The Testing of Portland Cements Containing Interground Vinsol Resin, 732.
Bland, Reginald B.
  Discussion, 905.
Blomquist, R. F.
  Types and Uses of Adhesives. Summary of Proceedings of the Symposium on Adhesives, 1023.
Bolton, J. W.
  Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, 92.
Bowman, J. J.
  Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought, 137.

Boxser, H.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Boyd, T. A.
Report of Committee D-2 on Petroleum Products and Lubricants, 228.

Boyer, R. F.
An Automatic Heat Distortion Recorder for Plastics. Published in the ASTM BULLETIN, No. 134, May, 1945, p. 37.

Boyle, C. J.
Magnetic Particle Inspection of Forgings. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Bradd, A. A.
Discussion, 441.

Bradshaw, W. H.
Standard Fatigue Tester for Use by the Rayon Manufacturers—Report to Committee D-13. Published in ASTM BULLETIN, No. 136, October, 1945, p. 13.

Brown, Hylton R.
Discussion, 876.

Brumfield, R. C.
A Sulfur Print Method for the Study of Crack Growth in the Corrosion-Fatigue of Metals, 544.

Bryant, C. B.
Report of Committee A-2 on Wrought Iron, 65.

Budd, C. B.
Statistical Comparison of Rayon Tire Cord Fatigue Testing Machines. Published in the ASTM BULLETIN, No. 136, October, 1945, p. 19.

Bulow, C. L.
Discussion, 613.

Burns, Robert
Dimensional Stability of Plastics, 926.
Report of Committee D-20 on Plastics, 369.

Burstein, H. N.
The Determination of the Terpene Alcohol Content of Steam-Distilled Pine Oil, 1015.

C

Carpenter, Arthur W.
Report of Committee D-11 on Rubber and Rubber-Like Materials, 312.

Carvajal, Jaime
The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics, 910.

Christian, A. F.
Fracture Testing of Alloy Steels for Aircraft Engine Forgings, 407. Discussion, 446.

Cizek, A. W., Jr.
A New Machine for Measuring Wear Resistance of Walkway Materials, 943.

Coe, Theodore I.
Report of Committee C-12 on Mortars for Unit Masonry, 213.

Collier, Simon
Report of Committee D-11 on Rubber and Rubber-Like Materials, 312.

Colwell, D. L.
Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought, 137.

Comley, M. A.
Discussion, 583.

Conner, R. M.
Report of Committee D-3 on Gaseous Fuels, 253.

Cook, Herbert K.
Automatic Accelerated Freezing-and-Thawing Apparatus for Concrete, 813.

Cope, E. T.
Report of Committee C-16 on Thermal Insulating Materials, 216.

Copson, H. R.
A Theory of the Mechanism of Rusting of Low Alloy Steels in the Atmosphere, 554. Discussion, 588.

Crossley, R. H.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Cunningham, E. N.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Curtis, H. L.
Report of Sectional Committee C-59 on Electrical Insulating Materials, 310.

D

Dahill, Edward
Report of Committee D-10 on Shipping Containers, 311.

Darrin, Marc
Discussion, 582.

Davis, Myron Park
Report of Committee D-9 on Electrical Insulating Materials, 275.

Dear, Paul S.
A Simplified Method for the Determination of the Specific Gravity of Wood and Plastics. Published in ASTM BULLETIN, No. 135, August, 1945, p. 35.

de Forest, A. V.
Equipment for Magnetic Particle Inspection. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Deppeler, J. H.
Report of Joint Committee on Filler Metal, 94.

Dietz, A. G. H.
Strength Properties (Subcommittee I). Summary of Proceedings of the Symposium on Adhesives, 1023.
Discussion, 907.

Dixon, E. O.
Magnetic Particle Testing of Aircraft Parts. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Dixon, J. B.
Report of Committee A-5 on Corrosion of Iron and Steel, 66.

Doner, S. R.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Douthett, W. L.
Report of Committee D-16 on Industrial Aromatic Hydrocarbons, 337.

Dunlap, M. E.
Methods Used for the Measurement of the Moisture Content of Wood. Appendix, Report of Committee D-7, 269.

Dwyer, John R.
The Testing of Portland Cements Containing Interground Vinsol Resin, 732.

E

Eberle, F.
Discussion, 504.

Edwards, Junius D.
A Comparison of the Performance of Anodic Coatings Exposed to Salt Spray and to the Weather. Appendix II, Report of Committee B-7, 146.

Erickson, E. C. O.
Discussion, 906.

Evans, W. A.
Report of Committee D-9 on Electrical Insulating Materials, 275.

Evans, W. S.
Discussion, 974.

F

Ferguson, H. P.
Introduction. Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 48.

Fernald, H. B.
Discussion, 444.

Fieldner, A. C.
Report of Committee D-5 on Coal and Coke, 255.

Findley, William N.
Fatigue Tests of a Laminated Mitscherlich-Paper Plastic, 878. Discussion, 908.

Fink, G. J.
Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars, 723.

Flint, F. C.
Glass—A Summary of Its Development as an Art and as a Science. Published in ASTM BULLETIN, No. 132, January, 1945, p. 19.

Foote, J. H.
Report of Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors, 96.

Frear, Clyde L.
Magnetic Powder Inspection of Castings. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

G

Gauger, A. W.
Report of Committee D-3 on Gaseous Fuels, 253.

Geil, G. W.
The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C., 448. Discussion, 483.

Goldberg, J. B.
Tomorrow's Textiles—Yesterday's Test Methods. Published in the ASTM BULLETIN, No. 135, August, 1945, p. 47.

Gottschalk, F. W.
Some Factors in the Interpretation of Small-Scale Tests for Fire-Retardant Wood. Published in ASTM BULLETIN, No. 136, October, 1945, p. 40.

Greenberg, S. A.
Report of Joint Committee on Filler Metal, 94.

Grinsfelder, Henry
Report of Committee D-14 on Adhesives, 335.

Grotlisch, V. E.
The Determination of the Terpene Alcohol Content of Steam-Distilled Pine Oil, 1015.
Report of Committee D-17 on Naval Stores, 349.

Grover, H. J.
Discussion, 542.

H

Hall, R. E.
Report of Committee D-19 on Water for Industrial Uses, 356.

Harnden, G. H.
Report of Committee B-5 on Copper and Copper Alloys, Cast and Wrought, 111.
Report of Committee D-6 on Paper and Paper Products, 257.

Harris, Jay C.
Metal Cleaning: I—Indirect Performance Tests, 985.
Metal Cleaning: II—Soil Removal Performance Methods, 997.

Harvey, Dean
Report of Committee B-4 on Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys, 108.

Haworth, R. D., Jr.
Fracture Testing of Alloy Steels for Aircraft Engine Forgings, 407. Discussion, 446.

Hecht, Max
Report of Committee D-19 on Water for Industrial Uses, 356.

Hedberg, James
Observations on the Appearance Welding of Malleable Castings, 618.

Heirholzer, George A.
An Automatic Heat Distortion Recorder for Plastics. Published in the ASTM BULLETIN, No. 134, May, 1945, p. 37.

Hemming, C. B.
Adhesive Working Qualities (Subcommittee IV). Summary of Proceedings of the Symposium on Adhesives, 1023.

Herndon, L. K.
Report of Committee C-7 on Lime, 203.

Hess, R. E.
Report of Committee E-10 on Standards, 395.
Report of Sectional Committee C-59 on Electrical Insulating Materials, 310.

Hocker, C. D.
Report of Committee A-5 on Corrosion of Iron and Steel, 66.
Report of Wire Inspection Committee, Committee A-5, on Field Tests of Wire and Wire Products, 70.

Holler, H. D.
Discussion, 582.

Hungerford, R. L.
The Effect of the Iron Content of Cupro-Nickel on its Corrosion Resistance in "Sea Water," 591. Discussion, 617.

I

Ingberg, S. H.
Report of Committee C-5 on Fire Tests of Materials and Construction, 201.
Test Criterion for an Incombustible Material, 866. Discussion, 877.

J

Jackson, L. R.
Discussion, 542.

Jasper, T. McLean
Discussion, 527, 904.

Jernstedt, George W.
Surface-Conversion Coatings. Published in ASTM BULLETIN, No. 137, December, 1945, p. 29.

Jones, L. B.
The Magnetic Particle Test as Utilized by the Railroads. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Jones, P. G.
Discussion, 482.

Juve, A. E.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

K

Kallas, D. H.
A New Machine for Measuring Wear Resistance of Walkway Materials, 943.

Kendall, E. H.
Report of Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors, 96.
Kenyon, John N.
An Automotive Tire Fatigue Machine. Published in the ASTM BULLETIN, No. 136, October, 1945, p. 9.
Kessler, D. W.
Discussion, 798.
Kilcawley, E. J.
Report of Committee D-18 on Soils for Engineering Purposes, 354.
Kirklin, W. A.
Report of Committee D-17 on Naval Stores, 349.
Kline, G. M.
A General Theory of Adhesion. Summary of Proceedings of the Symposium on Adhesives, 1023.
Kommers, J. B.
The Effect of Overstress in Fatigue on the Endurance Life of Steel, 532. Discussion, 542.

L

LaQue, F. L.
Discussion, 613.
Larrick, L.
Statistical Comparison of Rayon Tire Cord Fatigue Testing Machines. Published in the ASTM BULLETIN, No. 136, October, 1945, p. 19.
LaTour, Harry
Single-Strip Compression Test for Sheet Materials, 671. Discussion, 695.
Leaf, Walter
Discussion, 581.
Leavitt, H. Walter
Discussion, 810.
LeFevre, G. Howard
Report of Committee B-2 on Non-Ferrous Metals and Alloys, 102.
Lessells, John M.
Discussion, 444.
Lester, H. H.
Magnetic Particle Inspection. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.
Linn, F. C.
Neutralization Number from the Viewpoint of the Turbine Engineer—I. Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 50.
Lipson, S.
A New Coating Thickness Gage. Published in ASTM BULLETIN, No. 135, August, 1945, p. 20.
Liska, J. A.
The Effect of Specimen Shape on the Compressive Strength Properties of Laterally Supported Plywood Specimens, 935.
Litvin, Albert
Effect of Heat on Portland Cements Containing Vinsol Resin, 766.
Loane, C. M.
A Comparison of the Salt Method with A.S.T.M. Method for Determining the Acidity of Lubricating Oils. Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 55.
Lorig, C. H.
Discussion, 442, 626.
Lundell, G. E. F.
Report of Committee E-3 on Chemical Analysis of Metals, 391.
Lytle, A. R.
Discussion, 627.

M

Mack, David J.
The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid, 629.
Madden, Baxter C., Jr.
Discussion, 689.
Mahoney, C. H.
A Variable Cycle Alternate Immersion Corrosion Testing Machine, 719.
Manov, George G.
The pH of Some Standard Buffer Solutions from 0 to 60 C. and the Calibration of Glass Electrode pH Meters. Published in ASTM BULLETIN, No. 137, December, 1945, p. 25.
Markwardt, L. J.
Report of Committee D-7 on Wood, 265.
Mather, Bryant
Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete, 802. Discussion, 812.
McAdam, D. J., Jr.
The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C., 448. Discussion, 483.

McCartny, G. D.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

McConville, H. A.
Past History of A.S.T.M. Lubricating Grease Test Methods. Published in ASTM BULLETIN, No. 133, March, 1945, p. 29.

McDonald, J. C.
Compression Testing of Magnesium Alloy Sheet, 698.

McHenry, Douglas
A Rubber Housing for Waterproofing the Bonded-Wire Strain Gage. Published in ASTM BULLETIN, No. 133, March, 1945, p. 18.
Discussion, 793.

McKay, R. J.
Report of Committee B-8 on Electrodeposited Metallic Coatings, 149.

McWhorter, J. F.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Mebs, R. W.
The Effect of Combined Stresses on the Mechanical Properties of Steels Between Room Temperature and −188 C., 448. Discussion, 483.

Meyer, L. W. A.
Report of Committee D-20 on Plastics, 369.

Miller, Dalton G.
Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements. Report of the Working Committee on Sulfate Resistance, Appendix III, Committee C-1, 165.

Miller, James A.
Discussion, 694.

Miller, R. F.
Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice, 486. Discussion, 505.

Mochel, N. L.
Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, 92.

Moore, A. A.
Compression Testing of Magnesium Alloy Sheet, 698.

Moore, H. F.
Report of the Research Committee on Fatigue of Metals, 91.
A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel, 507. Discussion, 528.

Mougey, H. C.
Life Testing of Lubrication Oil. Published in ASTM BULLETIN, No. 132, January, 1945, p. 15.

Muhlenbruch, C. W.
The Effect of Repeated Loading on the Bond Strength of Concrete, 824.

N

Nestlen, H.
A New Machine for Measuring Wear Resistance of Walkway Materials, 943.

Newell, H. D.
Report of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, 87.

O

Osgood, Wm. R.
Discussion, 690.

P

Parsons, D. E.
Report of Committee C-15 on Manufactured Masonry Units, 214.

Pearce, W. T.
Report of Committee D-1 on Paint, Varnish, Lacquer, and Related Products, 220.

Peterson, R. E.
Relation Between Life Testing and Conventional Tests of Materials. Published in ASTM BULLETIN, No. 133, March, 1945, p. 9.
Discussion, 522.

Phelps, S. M.
Report of Committee C-8 on Refractories, 208.

Pickett, Gerald
Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders, 846. Discussion, 865.

Platow, R. C.
Strength Properties (Subcommittee I). Summary of Proceedings of the Symposium on Adhesives, 1023.

Plummer, Harry C.
Report of Committee C-12 on Mortars for Unit Masonry, 213.

Pope, C. L.
Neutralization Number from the Viewpoint of the Industrial Engineer. Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 48.

Pratt, Horace A.
A Comparison of Absorption and Soundness Tests on Maine Sands, 771.

Pray, H. A.
Report of Subcommittee II, Committee B-8, on Performance Tests, 152.

Proctor, George R.
The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics, 910.

Q

Quadt, R. A.
Cast-to-Size Impact Specimens for Aluminum Sand Casting Alloys, 705.

R

Rawdon, H. S.
Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, 105.

Reid, L. S.
Report of Committee D-6 on Paper and Paper Products, 257.

Reinhard, C. E.
Report of Subcommittee VIII, Committee A-5, on Field Tests of Metallic Coatings, 69.

Reinsmith, Gerald
Specifications for Adhesives (Subcommittee V). Summary of Proceedings of the Symposium on Adhesives, 1023.

Repsher, Leonard
Analytical Procedures Used on Adhesives (Subcommittee II). Summary of Proceedings of the Symposium on Adhesives, 1023.

Riedel, J. C.
Report of Committee C-4 on Clay Pipe, 200.

Rinker, R. C.
A General Theory of Adhesion. Summary of Proceedings of the Symposium on Adhesives, 1023.

Robinson, H. M.
Report of Committee C-5 on Fire Tests of Materials and Construction, 201.

Roehmann, L. F.
Electrical Conductivity of Conductors, 711.

Roehner, T. G.
Cooperative Committees Developing Test Methods for Lubricating Greases. Published in ASTM BULLETIN, No. 133, March, 1945, p. 31.

Rose, C. H.
Report of Committee D-1 on Paint, Varnish, Lacquer, and Related Products, 220.

Ruettgers, Arthur
Discussion, 794.

Rustay, A. L.
Discussion, 442.

S

Sample, C. H.
Report of Committee B-8 on Electrodeposited Metallic Coatings, 149.

Sanger, M.
High Temperature Oven Aging of Oil-Resisting Synthetic Rubber Compounds. Published in ASTM BULLETIN, No. 132, January, 1945, p. 33.

Schaefer, A. O.
Introduction. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.

Schoenborn, E. M.
The Effect of Width and of Span-Depth Ratio on the Flexural Strength of Laminated Plastics, 910. Discussion, 923.

Schofield, L. B.
Report on Results of Questionnaire to Utilities Relating to Tests on Transformer Oil in Service. Appendix III, Report of Subcommittee IV, Committee D-9, 302.

Schwartz, H. A.
Observations on the Appearance Welding of Malleable Castings, 618. Discussion, 628.

Scott, Robert G.
Report of Committee C-4 on Clay Pipe, 200.

Seemann, Herman E.
General Properties of Industrial Radiographic Films. Published in the ASTM BULLETIN, No. 134, May, 1945, p. 17.

Seliger, Victor
A Suggested New Parameter for Fatigue Strength Analysis. Published in ASTM BULLETIN, No. 132, January, 1945, p. 29.

Selvig, W. A.
Report of Committee D-5 on Coal and Coke, 255.

Setchkin, N. P.
Test Criterion for an Incombustible Material, 866. Discussion, 877.
Shank, J. R.
Discussion, 951.
Skeie, K. A.
A Variable Cycle Alternate Immersion Corrosion Testing Machine, 719.
Smith, G. V.
Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice, 486. Discussion, 505.
Smith, H. E.
Discussion, 581.
Smither, F. W.
Report of Committee D-12 on Soaps and Other Detergents, 319.
Snader, E. A.
Miscellaneous Applications of the Magnetic Particle Test. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.
Snyder, Charles G.
Report on Comparative Short-Time Tests for Sulfate Resistance of 121 Commercial Cements. Report of the Working Committee on Sulfate Resistance, Appendix III, Committee C-1, 165.
Speller, Frank N.
Memo on Cavitation. Published in ASTM BULLETIN, No. 133, March, 1945, p. 21.
Spooner, A. P.
Specifications and Procedure. Summary of Proceedings of the Philadelphia District Meeting—Symposium on Magnetic Particle Testing, 722.
Stern, E. George
A Simplified Method for the Determination of the Specific Gravity of Wood and Plastics. Published in ASTM BULLETIN, No. 135, August, 1945, p. 35.
Stillman, J. W.
Report of Committee E-3 on Chemical Analysis of Metals, 391.
Stivers, E. R.
Report of Committee D-10 on Shipping Containers, 311.
Strauss, Jerome
Report of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, 87.
Stroop, D. V.
Report of Committee D-2 on Petroleum Products and Lubricants, 228.
Sullivan, J. D.
Report of Committee C-8 on Refractories, 208.

T

Tarr, A. L.
A Variable Cycle Alternate Immersion Corrosion Testing Machine, 719.
Tarr, C. O.
Structural Changes in Carbon and Molybdenum Steels During Prolonged Heating at 900 to 1100 F., as Affected by Deoxidation Practice, 486. Discussion, 505.
Taylerson, Ewart S.
Report of Subcommittee III, Committee A-5, on Inspection of Annapolis Tests, 67.
Templin, R. L.
Discussion, 690, 960.
Terzaghi, K.
Stress Conditions for the Failure of Saturated Concrete and Rock, 777. Discussion, 800.
Thomas, Ray
Report of Committee C-16 on Thermal Insulating Materials, 216.
Thomson, William T.
Discussion, 864.
Thum, E. E.
Report of Committee B-2 on Non-Ferrous Metals and Alloys, 102.
Townsend, J. R.
Report of Committee B-6 on Die-Cast Metals and Alloys, 134.
Discussion, 689.
Tracy, A. W.
The Effect of the Iron Content of Cupro-Nickel on its Corrosion Resistance in "Sea Water," 591. Discussion, 617.
Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, 105.
Trattner, Emil
Properties of Highly Hydrated Dolomitic Masonry Limes and Certain of Their Cement-Lime Mortars, 723.
Trostel, L. J.
Report of Committee C-8 on Refractories, 208.
Truax, T. R.
Report of Committee D-14 on Adhesives, 335.
Types and Uses of Adhesives. Summary of Proceedings of the Symposium on Adhesives, 1023.

Tucker, John, Jr.
Effect of Dimensions of Specimens upon the Precision of Strength Data, 952. Discussion, 960.
Discussion, 811.
Effect of Length on the Strength of Compression Test Specimens, 976.
The Maximum Stresses Present at Failure of Brittle Materials, 961. Discussion, 975.
Turner, Philip S.
Discussion, 389, 923.

V

Valle-Rodas, Raul
A New Method for the Mechanical Analysis of Soils. Published in ASTM BULLETIN, No. 135, August, 1945, p. 44.
Van Zile, B. S.
Report of Committee D-12 on Soaps and Other Detergents, 319.
Vassar, H. S.
Report of Committee E-10 on Standards, 395.
Vasta, J.
Discussion, 667.
Veal, C. B.
Report of Technical Committee A on Gasoline, Committee D-2 on Petroleum Products and Lubricants, 233.
Venable, C. S.
Comparative Fatigue Test Data. Published in ASTM BULLETIN, No. 136, October, 1945, p. 17.
Vennerholm, G.
Discussion, 626.
Vernon, K. F.
Report of Committee D-18 on Soils for Engineering Purposes, 354.
Vernon, W. H. J.
Discussion, 586.
Von Fuchs, G. H.
Neutralization Number from the Viewpoint of the Turbine Engineer—II. Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 51.
von Schrenk, Hermann
Report of Committee D-7 on Wood, 265.
Voss, W. C.
Report of Committee C-7 on Lime, 203.

W

Walters, E. L.
Determination of Gum Values by the I.P.T. and A.S.T.M. Air Jet Gum Methods. Published in ASTM BULLETIN, No. 135, August, 1945, p. 40.
Warren, G. E.
Report of Committee C-1 on Cement, 156.
Warwick, C. L.
Annual Report of the Executive Committee, 21.
Weaver, V. P.
Report of Committee B-5 on Copper and Copper Alloys, Cast and Wrought, 111.
Wehmer, Fred
Permanence Tests of Adhesive Bonds (Subcommittee III). Summary of Proceedings of the Symposium on Adhesives, 1023.
Weiss, J. M.
Report of Committee D-16 on Industrial Aromatic Hydrocarbons, 337.
Welter, G.
Discussion, 693.
Werley, G. L.
Report of Committee B-6 on Die-Cast Metals and Alloys, 134.
Whitcomb, W. H.
Report of Committee D-13 on Textile Materials, 323.
Whittemore, J. W.
Report of Committee C-15 on Manufactured Masonry Units, 214.
Wing, S. P.
Discussion, 794.
Withey, M. O.
Discussion, 810.
Wolf, H. R.
Neutralization Number from the Viewpoint of the Automotive Engineer. Symposium on Neutralization Number. Published in ASTM BULLETIN, No. 134, May, 1945, p. 52.
Wolford, Don S.
Single-Strip Compression Test for Sheet Materials, 671. Discussion, 695.
Wright, E. C.
The Manufacture of Heavy-Wall Pipe $12\frac{3}{4}$ to 24 In. Outside Diameter. Published in ASTM BULLETIN, No. 133, March, 1945, p. 19.
Wuerpel, Charles E.
Automatic Accelerated Freezing-and-Thawing Apparatus for Concrete, 813.
Discussion, 753.

Y

Yabroff, D. L.
Determination of Gum Values by the I.P.T. and A.S.T.M. Air Jet Gum Methods. Published in ASTM BULLETIN, No. 135, August, 1945, p. 40.

Yates, Jason C.
The Testing of Portland Cements Containing Interground Vinsol Resin, 732.

Young, Ira
Observations on the Appearance Welding of Malleable Castings, 618.

Z

Zinzow, W. A.
Flexural Properties of Plastics—Summary of Test Results Obtained in Committee D-20. Appendix II, Report of Committee D-20, 376.
Report of Committee D-9 on Electrical Insulating Materials, 275.